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RESULTS OF SHEAR TESTING ON PARADISE RIVER SPECIMENS

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RESULTS OF SHEAR TESTING ON PARADISE RIVER SPECIMENS

by

Rand Jackson*

ABSTRACT

Direct shear tests were performed on four intact banded tuff specimens obtained from the Paradise River hydro-electric project by ShawMont Newfoundland Limited. The specimens were initially sheared along kink bands running perpendicular to the schistosity at normal loads of 200, 500, 1000 and 2000 kPa. Having sheared an intact specimen at its respective normal stress, the resulting shear plane was subjected to a normal stress of 200 kPa and sheared in the opposite direction. This was subsequently repeated for normal stresses of 500, 1000 and 2000 kPa.

Peak shear strengths of 2277, 4097, 4929 and 6610 kPa were determined for normal stresses 200, 500, 1000 and 2000 kPa, respectively. The intact material was found to have an angle of internal friction of 59° and cohesion intercept of 3256 kPa. Mean residual shear strengths of 214, 395, 1138 and 1335 kPa were obtained for the normal stresses listed above.

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Keywords

Shear Tests, Banded Tuff, ShawMont Newfoundland Ltd., Shear Strength, Residual Shear Strength, Angle of Internal Friction, Cohesion

RÉSULTATS OBTENUS DES ESSAIS DE CISAILLEMENT RÉALISÉS AVEC DES ÉCHANTILLONS DE PARADISE RIVER

par

Rand Jackson*

RÉSUMÉ

Des essais de cisaillement continus ont été réalisés avec quatre échantillons intacts de tuf stratifié provenant du projet hydro-électrique de Paradise River de la ShawMont Newfoundland Limited. Au début des essais, les échantillons ont été cisailés le long des plis anguleux dissymétriques perpendiculaires à la schistosité, à des charges normales de 200, 500, 1 000 et 2 000 kPa. Après avoir cisailé un échantillon intact à son niveau de contrainte normal respectif, la surface de cisaillement obtenue a été soumise à une contrainte normale de 200 kPa et cisailée dans le sens opposé. Cette étape a été répétée par la suite en utilisant les contraintes normales de 500, 1 000, et 2 000 kPa.

La résistance maximale au cisaillement a été calculée à 2 277, 4 097, 4 929 et 6 610 kPa pour les contraintes normales de 200, 500, 1 000 et 2 000 kPa respectivement. Il a été constaté que l'angle de frottement interne du matériau intact était de 59° et la cohésion de 3 256 kPa. Les valeurs moyennes de la résistance résiduelle au cisaillement de 214, 395, 1 138 et 1 335 kPa ont été obtenues pour les contraintes normales susmentionnées.

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Mots-clés : Essais de cisaillement, tuf stratifié, ShawMont Newfoundland Ltd., résistance au cisaillement, résistance résiduelle au cisaillement, angle de frottement interne, cohésion.

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INTRODUCTION

Direct shear tests were performed on four intact specimens obtained from the Paradise River hydro-electric project by ShawMont Newfoundland Limited. In addition, after the intact specimen was sheared, the resulting failure plane was loaded and sheared under four successive normal loads ranging from 200 to 2000 kPa. It is the purpose of this report to summarize the results of the testing and analyses.

SPECIMEN IDENTIFICATION AND PREPARATION

Two 200mm diameter cores of a kink banded tuff with schistosity running parallel to the core axis were provided for testing. They were previously designated as samples P.R. #5 and P.R. #6. Discs with a thickness equal to the final specimen width were cut from these by a water-cooled slab saw. The discs were, in turn, cut to the final specimen dimensions such that the anticipated plane of shearing coincided with a kink band running perpendicular to the schistosity. The final dimensions of each specimen as well as the cross-sectional area of the shear planes are summarized in Table 1. The kink band which was to be sheared was highlighted prior to testing with an indelible marker.

Detailed test specifications supplied by the contractor are included as an appendix to this report.

DESCRIPTION OF TEST MEASUREMENTS

Direct shear tests were conducted on the four Paradise River specimens using a constant displacement shear box designed and fabricated by CANMET (see Figure 1). The bottom half of the box provides the shearing motion while the top box is constrained to move vertically only. Normal load is applied by a hydraulic jack attached to a yoke spanning the center of gravity of the upper box. The hydraulic jack is connected to a pressure compensator which enables the piston to retract or extend to accommodate normal displacements during testing without changing the normal load. Shear force is provided by a 50 kN screw type actuator. The actuator reaction arm is instrumented with a full strain gauge bridge and calibrated against a Wykeham Farrance Model 14240 proving ring to provide an analogue signal of the shear load. Normal displacement is measured using two linear variable differential transducers (lvdt's) attached via magnetic stands to the hydraulic jack yoke on either side of the box. Shear displacement is also measured using an lvdt mounted on the end of the shear box. Analogue signals from the three lvdt's, the full bridge load cell and the pressure compensator are fed to a Fluke 2280A data logger with simultaneous readings being taken every four seconds.

Samples were initially positioned in the upper box in such a way that the center of the anticipated shear surface coincided with the center of gravity of the box and line of action of the normal loading system (see Figure 2). A quick setting, high strength cement (Hydrostone) was then poured to the top of the box and allowed to cure for 24 hours. After the cement had set sufficiently, the box/sample assembly was inverted and placed in position over the lower box with 12mm spacers between the two boxes. Cement was then poured into the bottom box and allowed to cure for an additional 48 hours. Spacers were then removed, instrumentation installed, normal load sufficient to affect the desired normal stress applied and the test commenced.

Four intact samples were sheared at a rate of 1.0 mm/sec with normal stresses of 200, 500, 1000 and 2000 kPa, respectively, until failure, at which point the shear displacement was stopped. The normal stress was then adjusted to 200 kPa and the failed sample sheared in the reverse direction at a constant displacement rate of 3.3 mm/sec. After sufficient displacement, the normal stress was adjusted to 500 kPa and the sample sheared in the opposite direction. This process was subsequently repeated at normal stresses of 1000 and 2000 kPa.

DATA SUMMARY

Table 1 contains a summary of the intact shear properties including sample name, dimensions, normal stress and peak shear strength for each specimen. Table 2 summarizes the residual shear strength and friction angles for each test configuration.

Figures 3 through 6 represent the shear force versus shear displacement curves for the intact specimens while Figures 7 through 22 present the same information for the sheared samples. The normal displacement versus shear displacement curves for the failed specimens are contained in Figures 23 to 38. Figure 39 represents a plot of the peak shear load versus normal pressure for the intact specimens. Figure 40 plots residual shear stress vs normal stress for the sheared specimens. Figures 41 through 44 are the before and after shearing pictures of samples PR 6-1, 6-2, 6-3 and 5-1 respectively.

Data reduction conformed with procedures outlined in CANMET's Pit Slope Manual.†

† Gyenge, M. and Herget, G. Pit Slope Manual Supplement 3-2 - Laboratory Tests for Design Parameters; CANMET (Canada Centre for Mineral and Energy Technology, CANMET Report 77-26; 74 p; May 1977.

Table 1: Summary of Sample Number, Dimensions, Normal Stress and Maximum Shear Stress

Sample Number	Dimensions		Cross-sectional Area (cm ²)	Normal Stress (kPa)	Maximum Shear Stress (kPa)
	Length (cm)	Width (cm)			
PR 6-1	14.620	8.768	128.188	200	2277
PR 6-2	14.589	8.183	119.374	500	4097
PR 6-3	8.737	7.235	63.212	1000	4929
PR 5-1	8.917	7.030	57.626	2000	6610

OBSERVATIONS AND CONCLUSIONS

As is evident from Table 1, it was necessary to reduce the cross-sectional area of the intact specimens for the higher normal stresses of 1000 and 2000 kPa. This was due to the limited capacity of the shearing actuator and, while it is not addressed in this report, there may be some scale effects that might be considered.

Shear tests conducted on the intact specimens yield an apparent angle of internal friction of 59° and a cohesion intercept of 3256 kPa. The shear strength observed at a normal stress of 200 kPa, however, deviates considerably from this envelope and suggests that the kink band of that specimen chosen for shearing may have already been partially failed. Unfortunately, a cursory literature search revealed little shear work done on tuffs perpendicular to the schistosity with which to compare these results.

The method of shearing the failed samples with increasingly higher normal stresses results in a considerable amount of gouge being produced by each successive shearing. It is apparent that while the tests at a normal stress of 200 kPa are being conducted on relatively clean, mechanical joints, those conducted at 1000 and 2000 kPa may include factors such as rolling friction caused by the increased infilling material. This behaviour is indicated by the decreasing residual friction angle observed with increasing normal loading (see Figure 40). Again, the effect is difficult to quantify but it seems reasonable to assume that higher residual stresses would be observed if the 1000 and 2000 kPa tests were conducted on fresh surfaces.

Table 2: Joint Properties for the Sheared Paradise River Specimens

Sample Number	Normal Stress (kPa)	Peak Shear Strength (kPa)	Residual Shear Strength (kPa)	Effective Dilatancy	ϕ_p	ϕ_r	ϕ_b
PR 6-1	200	423	238	11°	65°	50°	39°
	500	538	382	10°	47°	37°	27°
	1000	1620	1460	4°	58°	56°	52°
	2000	1515	1515	6°	37°	37°	31°
PR 6-2	200	415	180	18°	64°	42°	24°
	500	836	550	11°	59°	48°	37°
	1000	1115	825	12°	48°	40°	28°
	2000	2436	1380	7°	51°	35°	28°
PR 6-3	200	451	180	9°	66°	42°	33°
	500	364	331	17°	36°	34°	17°
	1000	1328	1050	n/a	53°	46°	n/a
	2000	1175	715	12°	30°	20°	8°
PR 5-1	200	491	258	n/a	68°	52°	n/a
	500	428	318	17°	41°	32°	15°
	1000	1638	1215	n/a	59°	51°	n/a
	2000	1766	1730	9°	41°	31°	22°

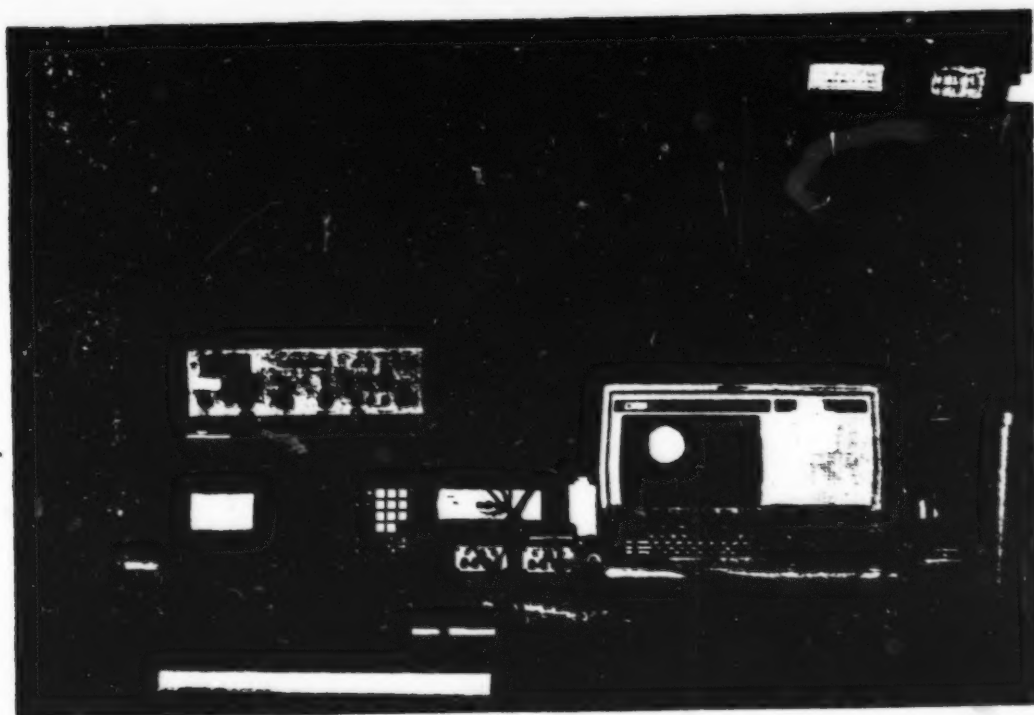
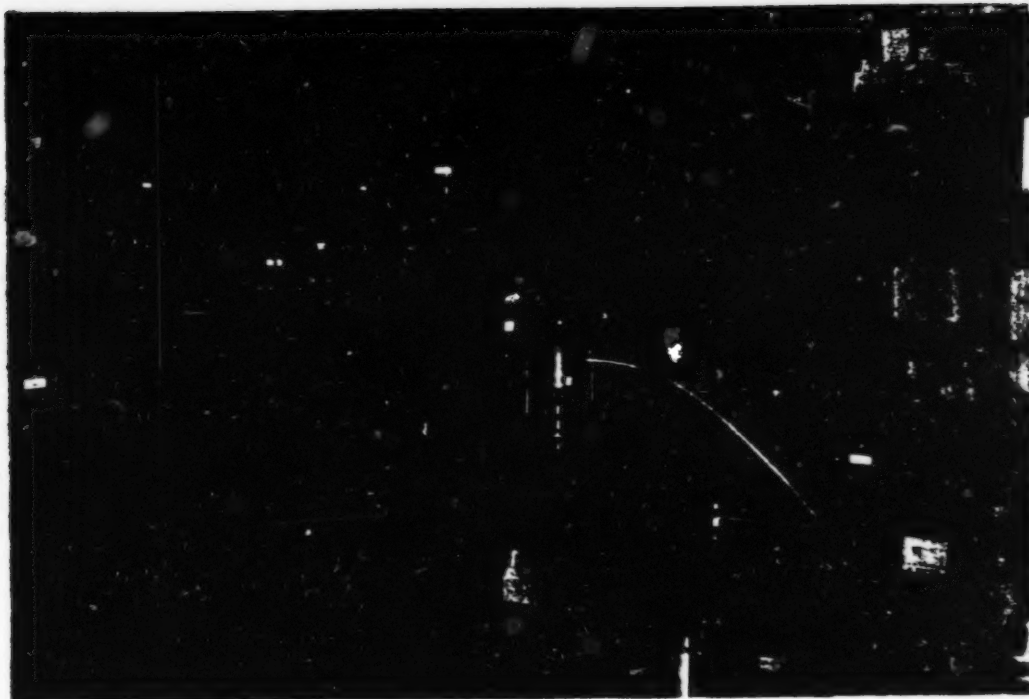


Figure 1: Direct Shear Box and Data Logging Equipment

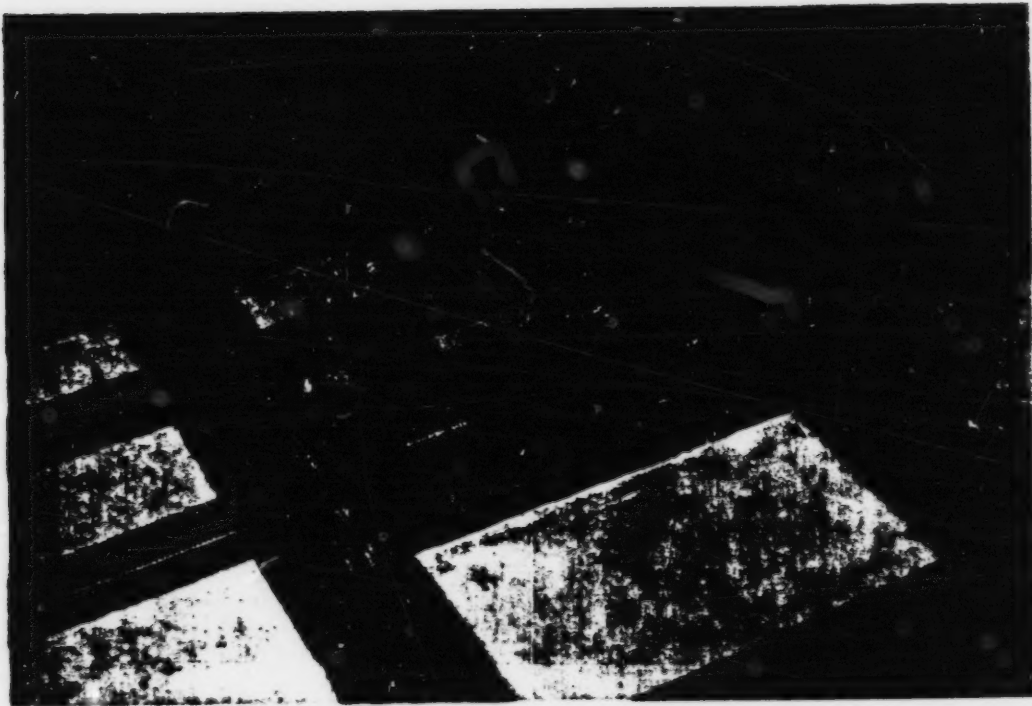
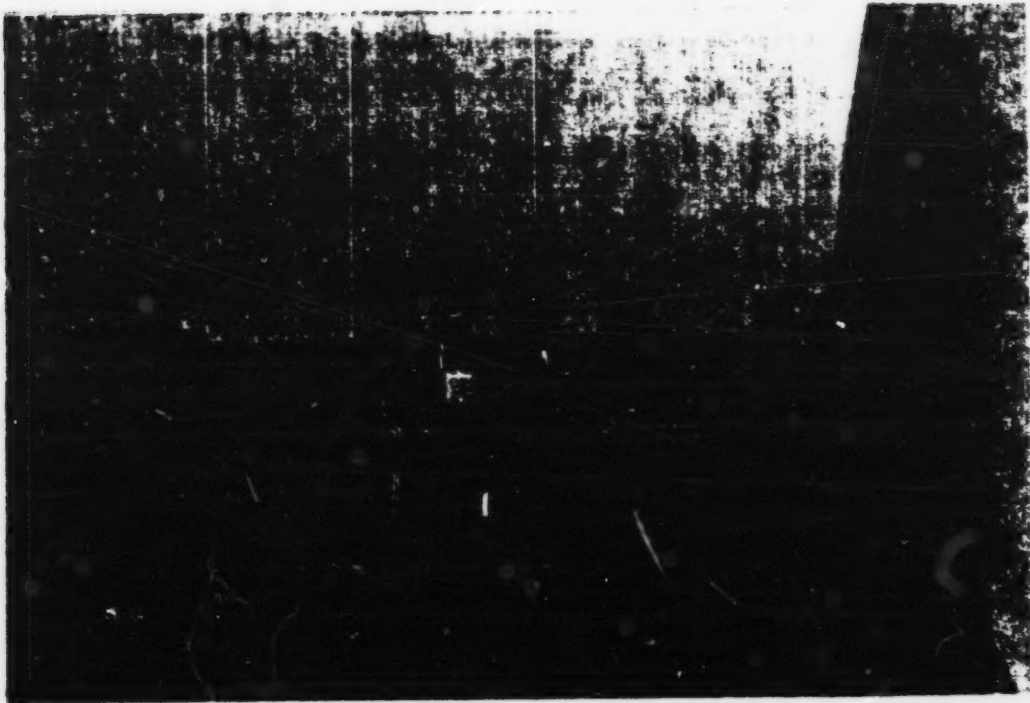


Figure 2: Positioning Sample in Upper Shear Box

SHEAR FORCE VS DISPLACEMENT: INTACT PARADISE RIVER SPECIMENS

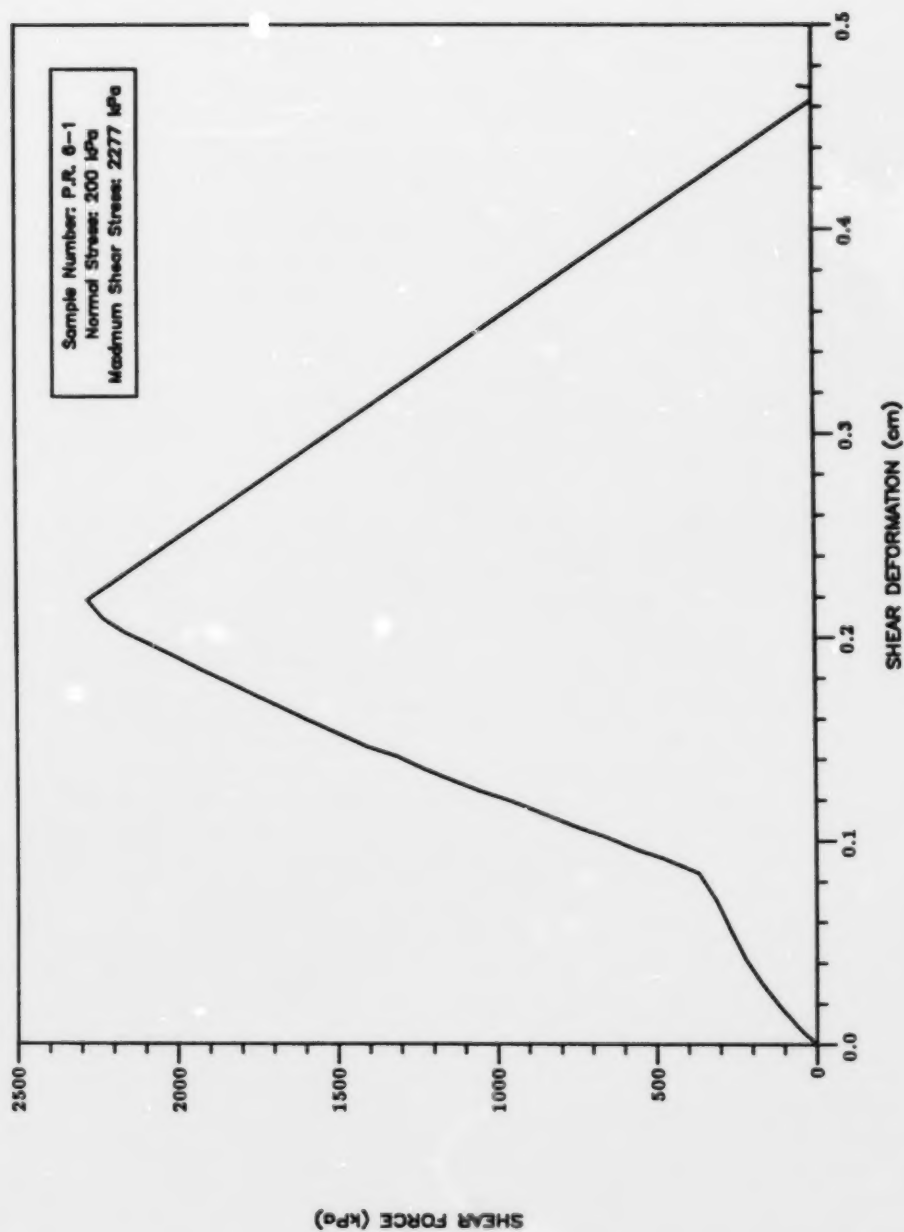


FIGURE 3

SHEAR FORCE VS DISPLACEMENT: INTACT PARADISE RIVER SPECIMENS

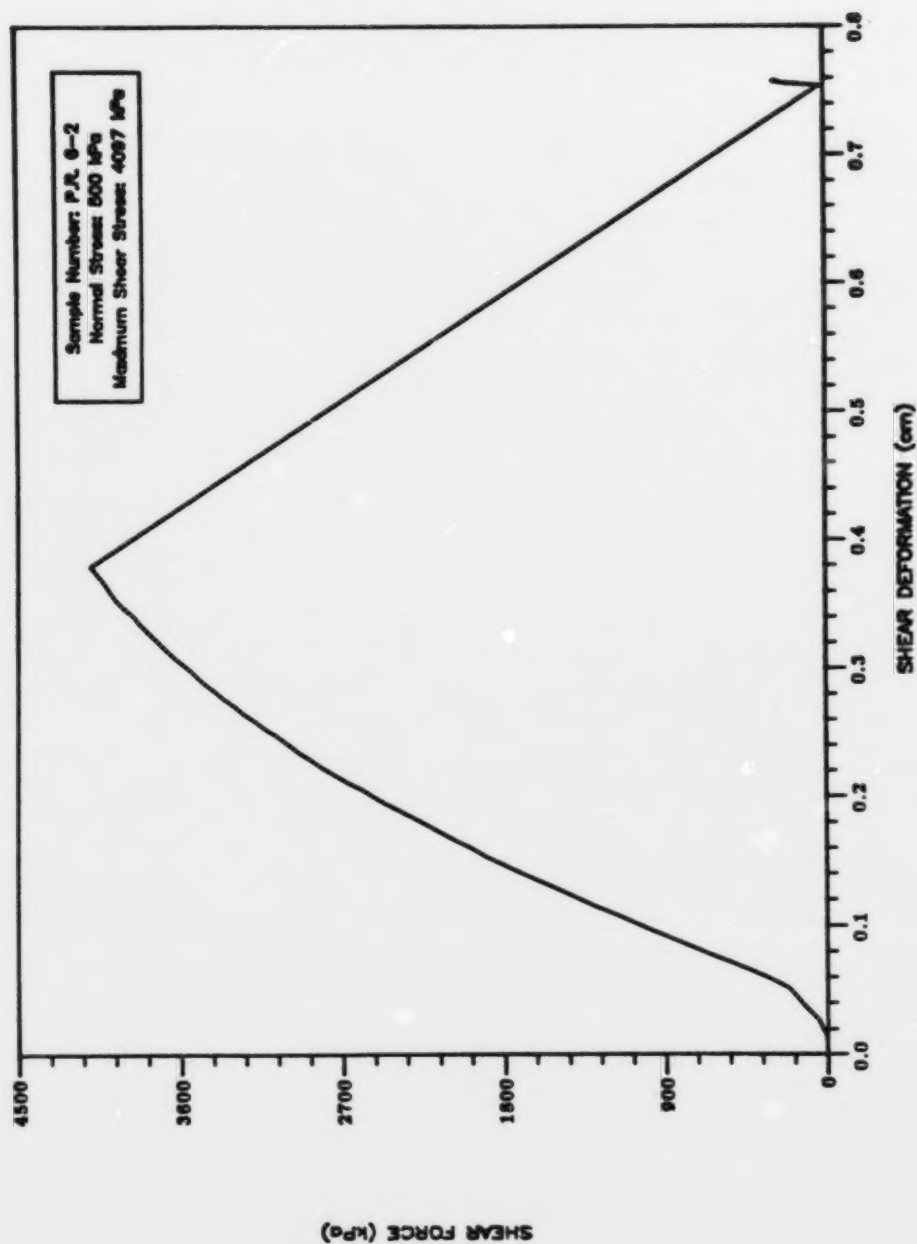


FIGURE 4

SHEAR FORCE VS DISPLACEMENT: INTACT PARADISE RIVER SPECIMENS

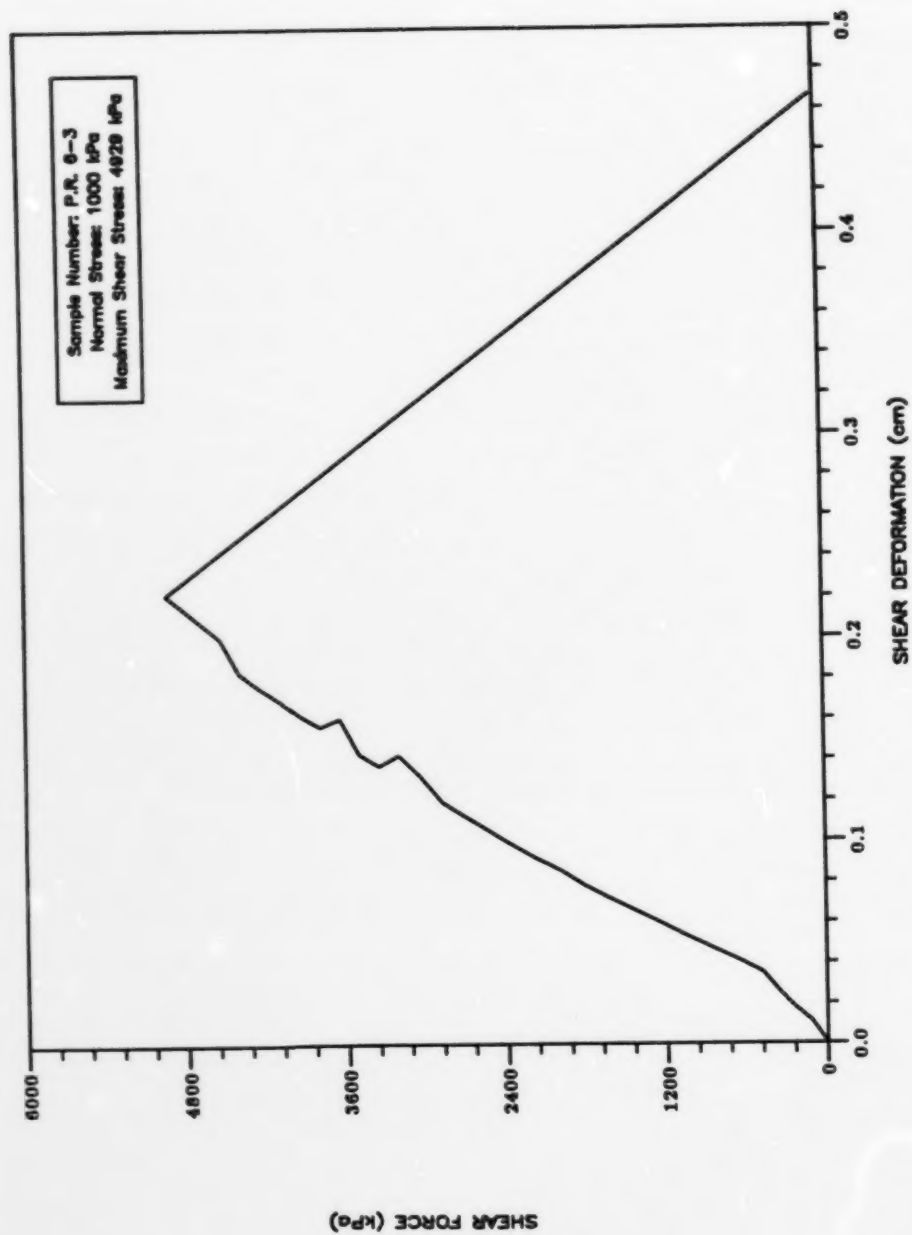


FIGURE 5

SHEAR FORCE VS DISPLACEMENT: INTACT PARADISE RIVER SPECIMENS

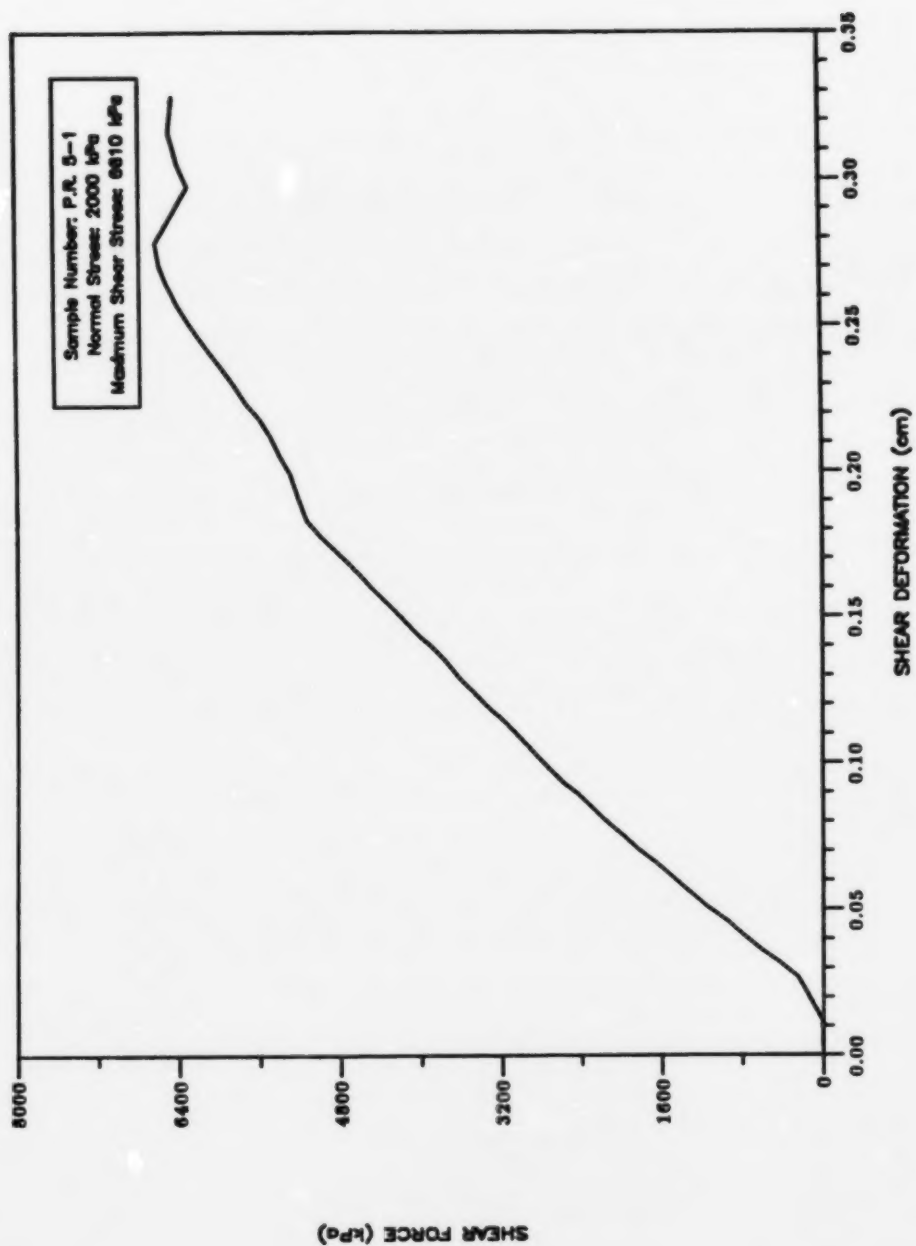
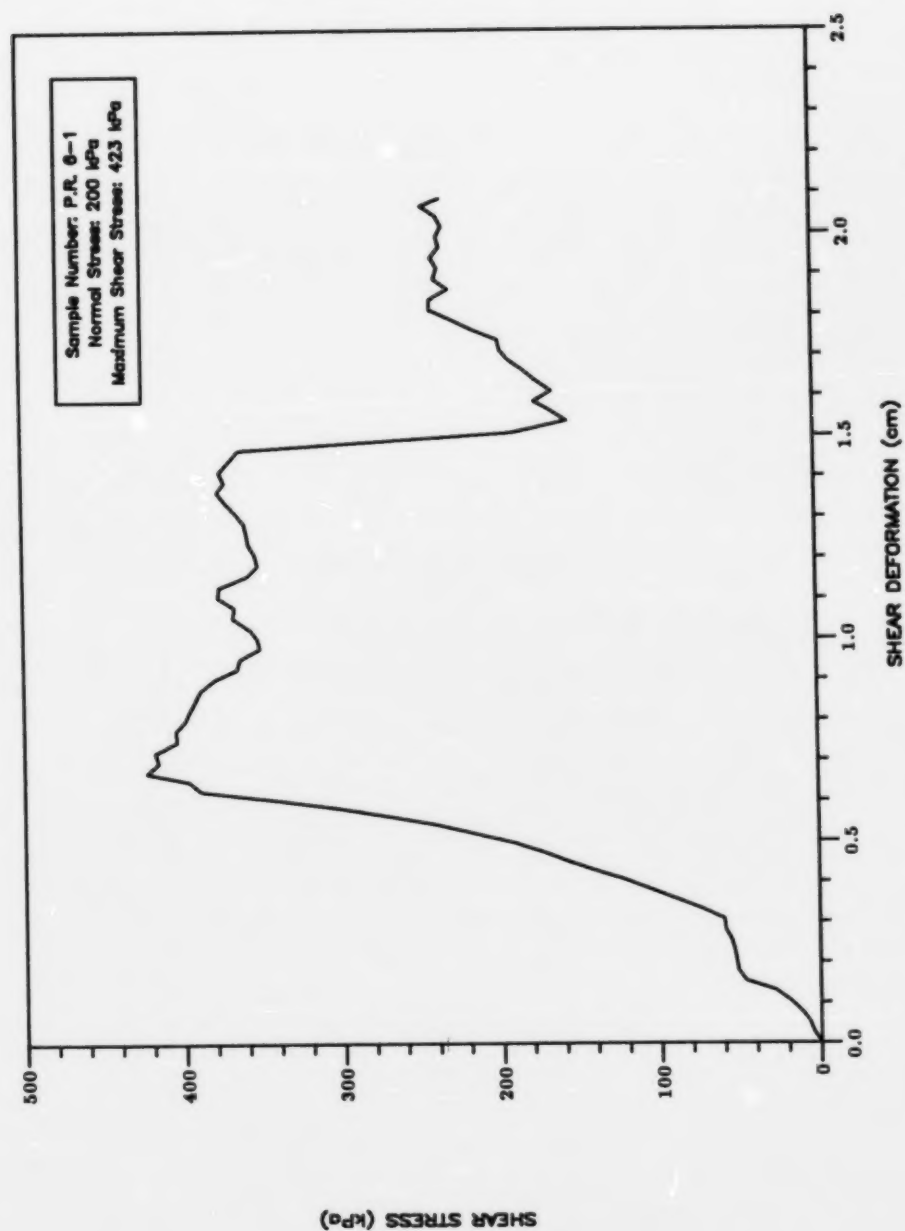


FIGURE 6

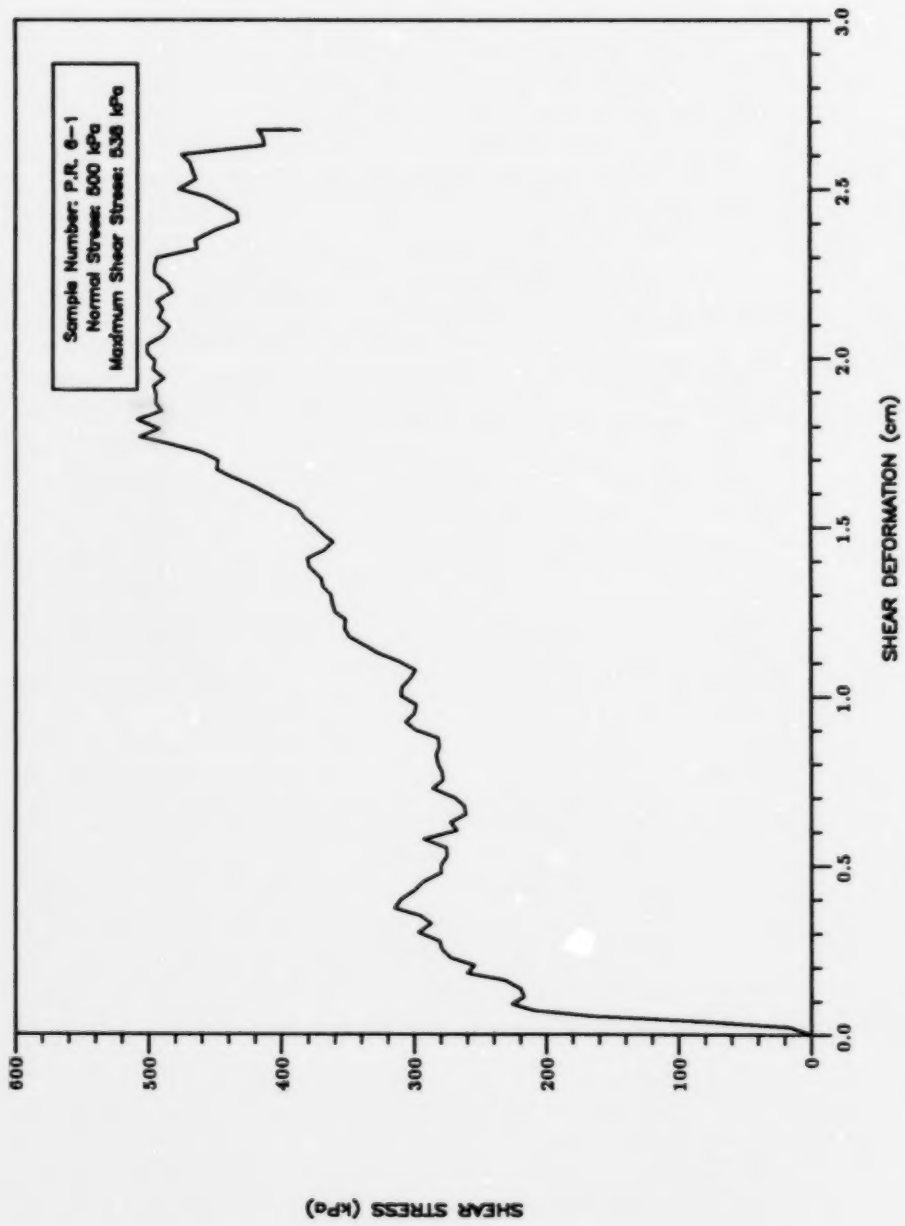
SHEAR STRESS VS DISPLACEMENT: SHEARED PARADISE RIVER SPECIMENS



Note: Direction of shearing was opposite that used for the intact specimen.

FIGURE 7

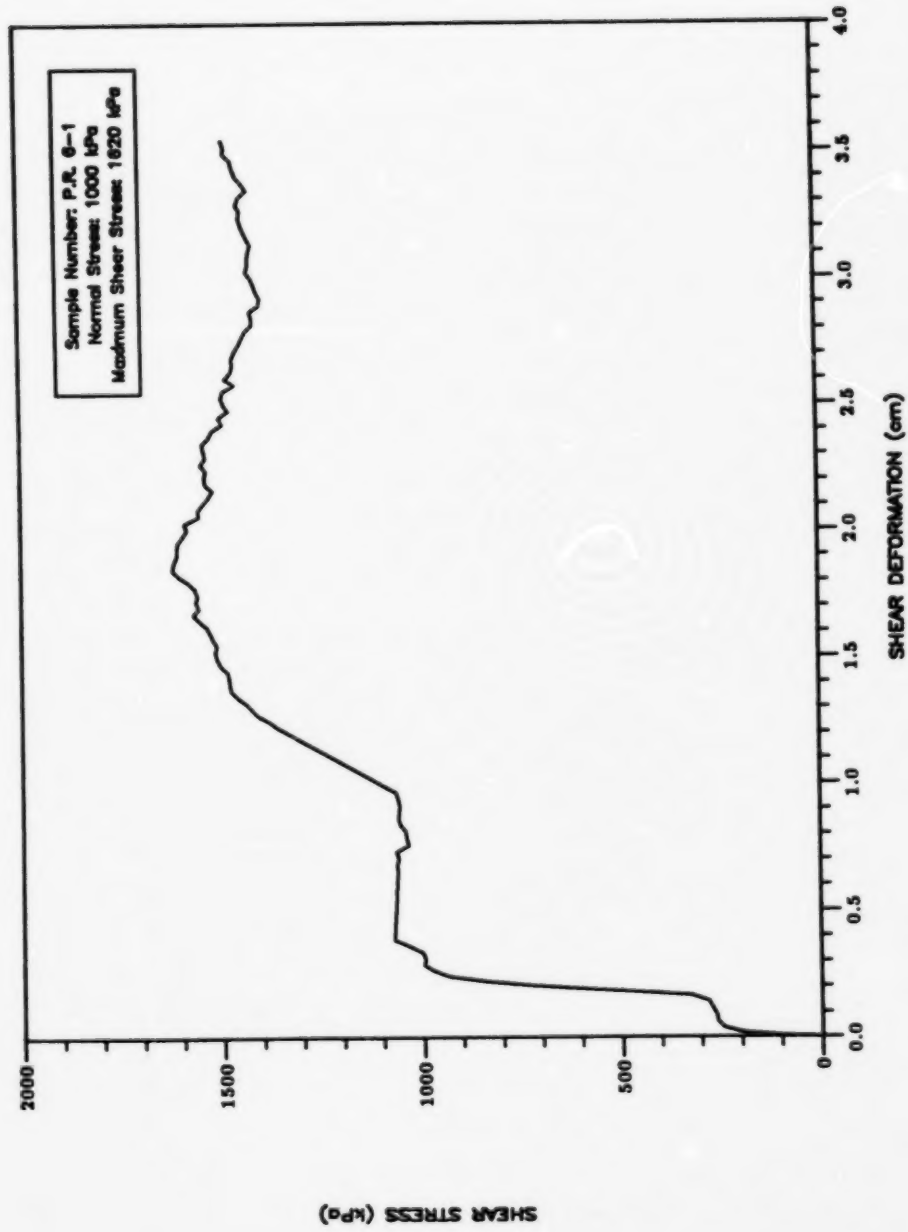
SHEAR STRESS VS DISPLACEMENT: SHEARED PARADISE RIVER SPECIMENS



Note: Direction of shearing was the same as that used for the intact specimen.

FIGURE 8

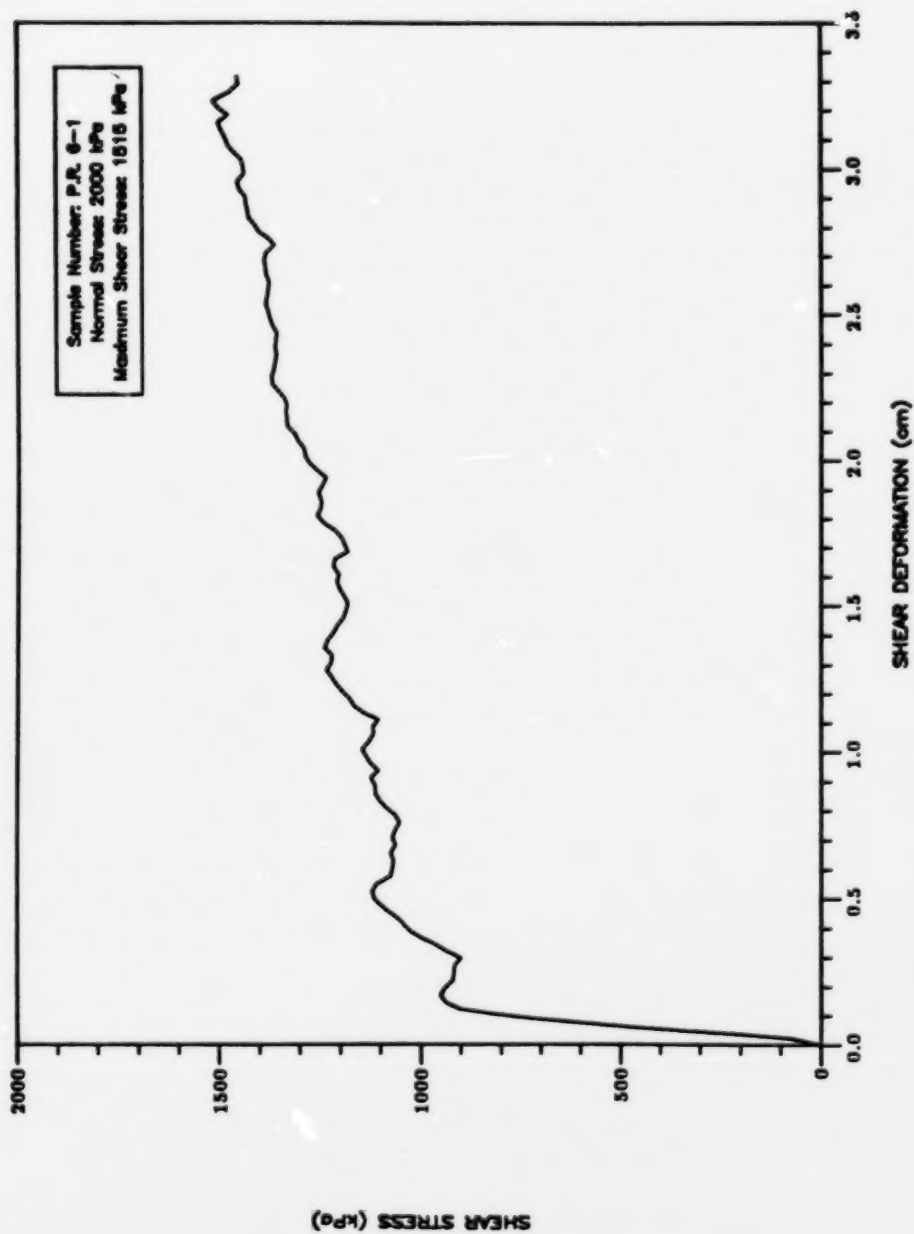
SHEAR STRESS VS DISPLACEMENT: SHEARED PARADISE RIVER SPECIMENS



Note: Direction of shearing was opposite that used for the intact specimen.

FIGURE 9

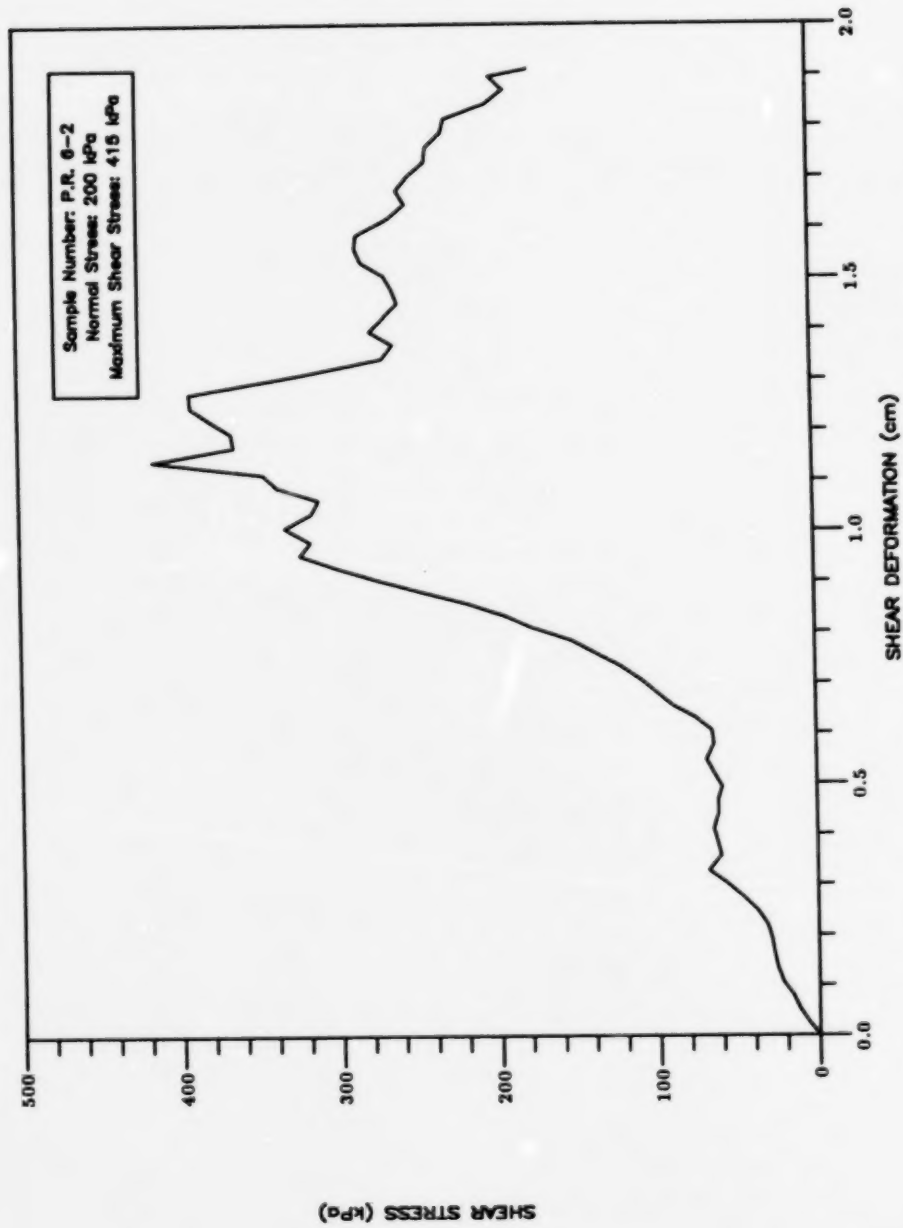
SHEAR STRESS VS DISPLACEMENT: SHEARED PARADISE RIVER SPECIMENS



Note: Direction of shearing was the same as that used for the intact specimen.

FIGURE 10

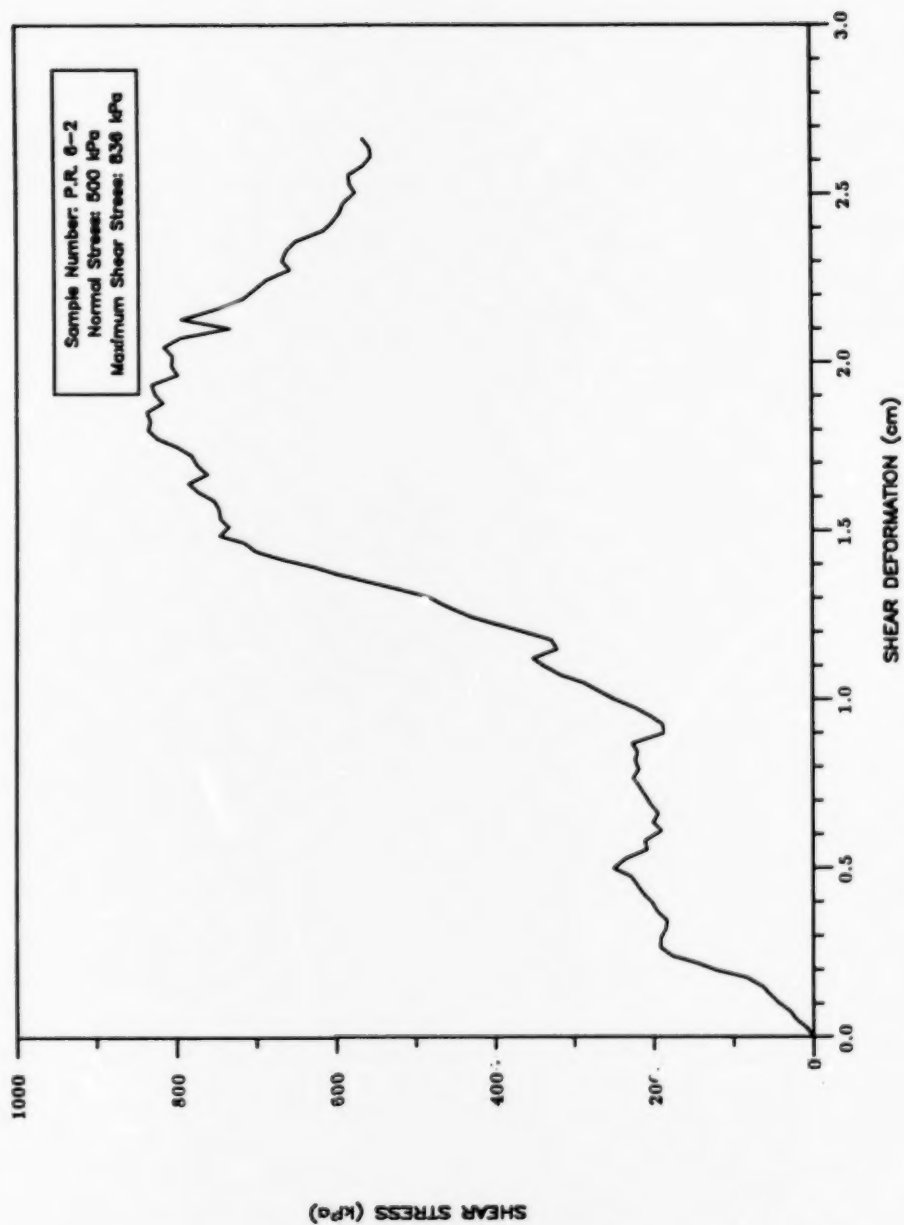
SHEAR STRESS VS DISPLACEMENT: SHEARED PARADISE RIVER SPECIMENS



Note: Direction of shearing was opposite that used for the intact specimen.

FIGURE 11

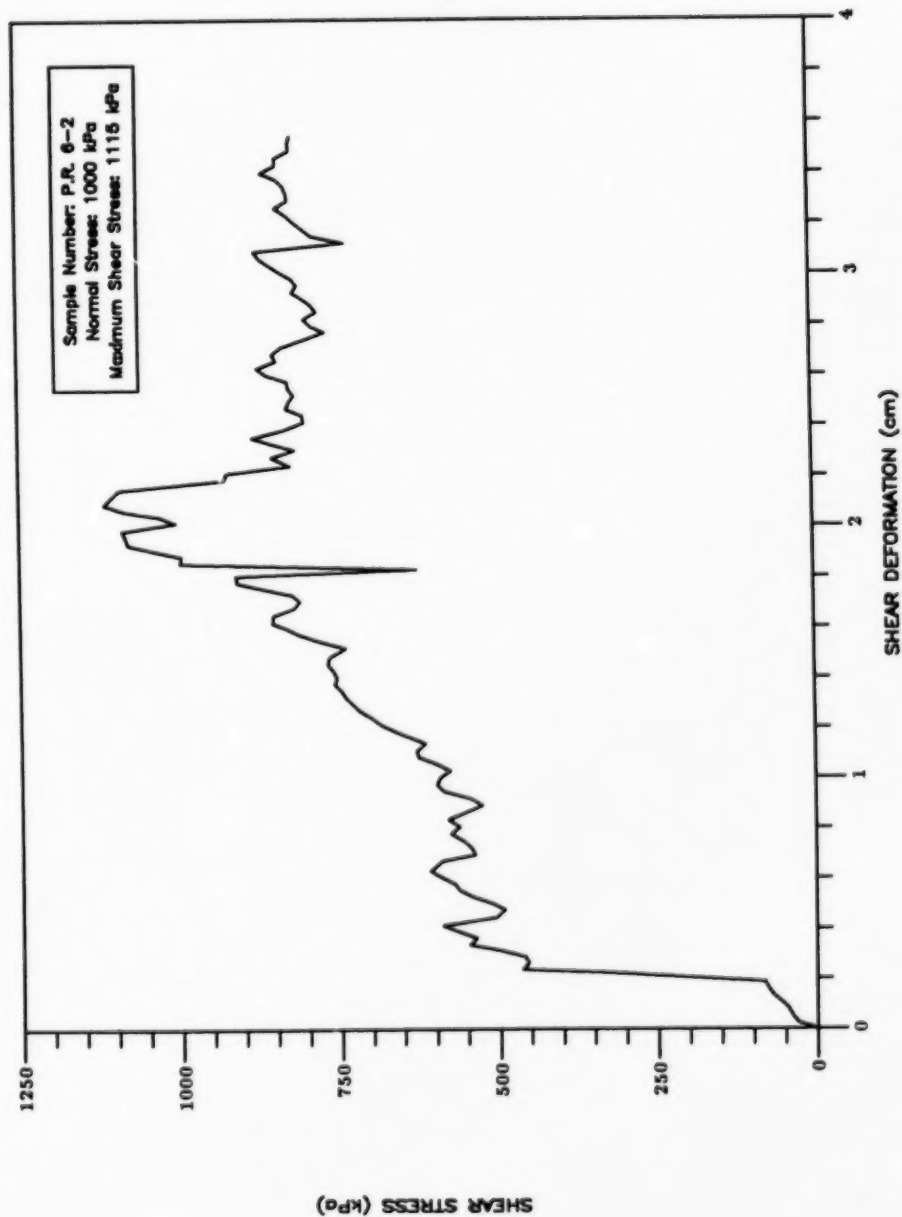
SHEAR STRESS VS DISPLACEMENT: SHEARED PARADISE RIVER SPECIMENS



Note: Direction of shearing was the same as that used for the intact specimen.

FIGURE 12

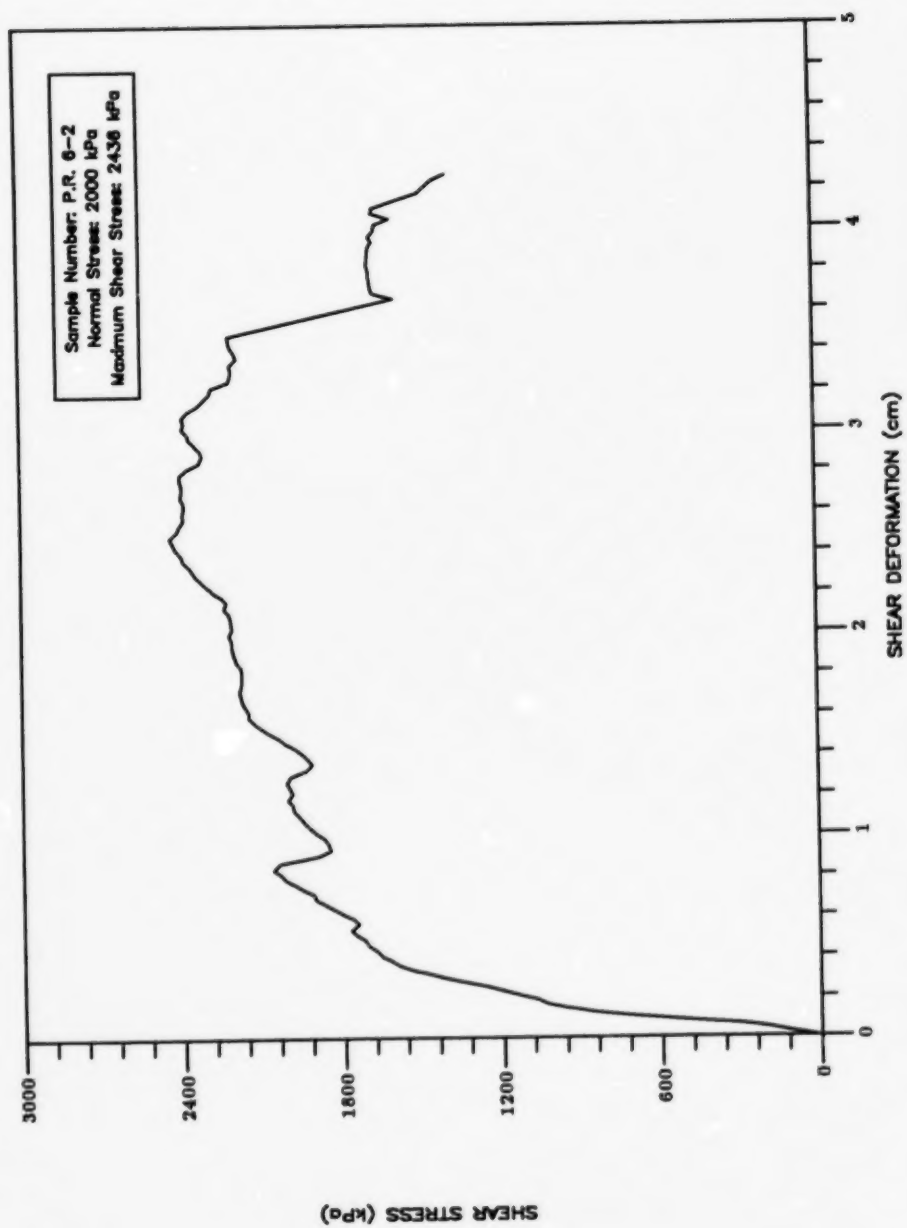
SHEAR STRESS VS DISPLACEMENT: SHEARED PARADISE RIVER SPECIMENS



Note: Direction of shearing was opposite that used for the intact specimen.

FIGURE 13

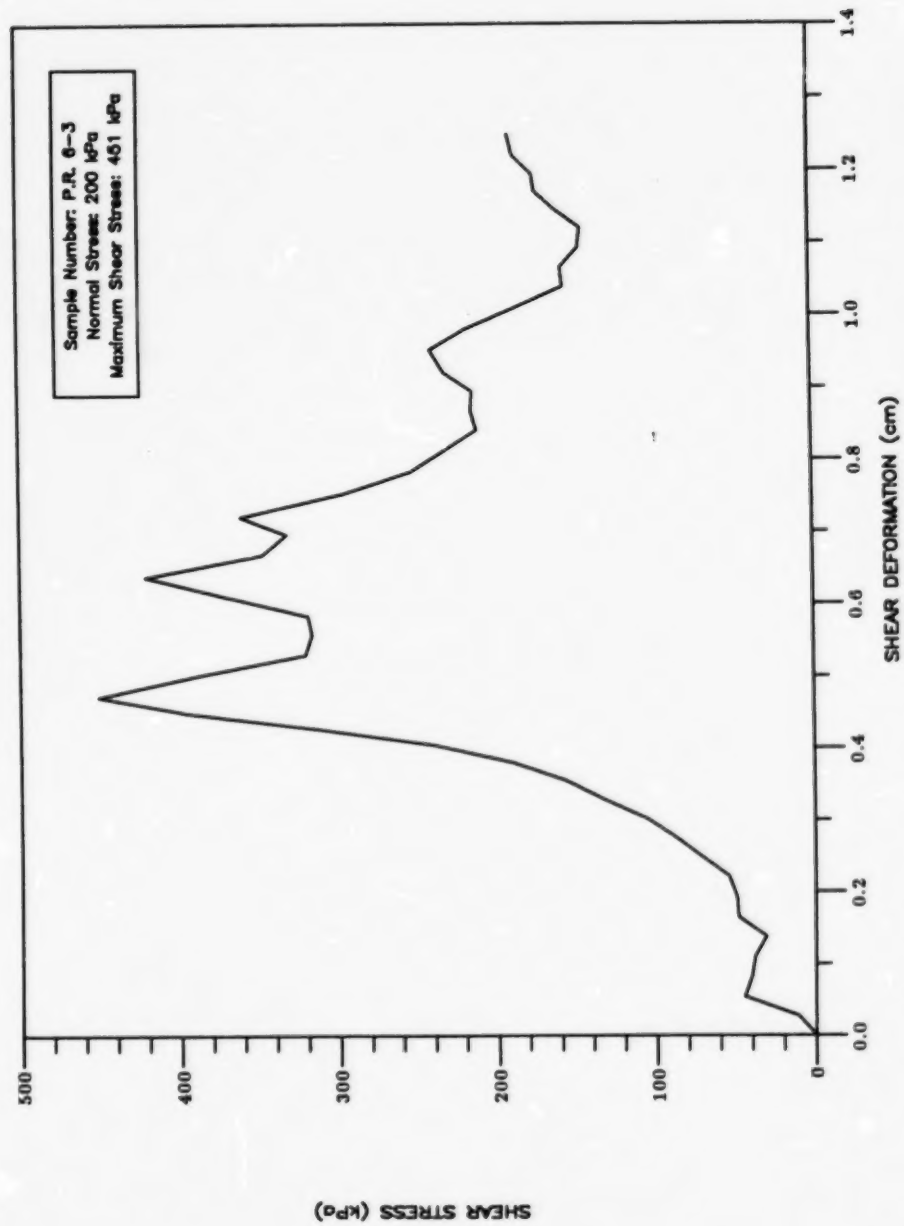
SHEAR STRESS VS DISPLACEMENT: SHEARED PARADISE RIVER SPECIMENS



Note: Direction of shearing was the same as that used for the intact specimen.

FIGURE 14

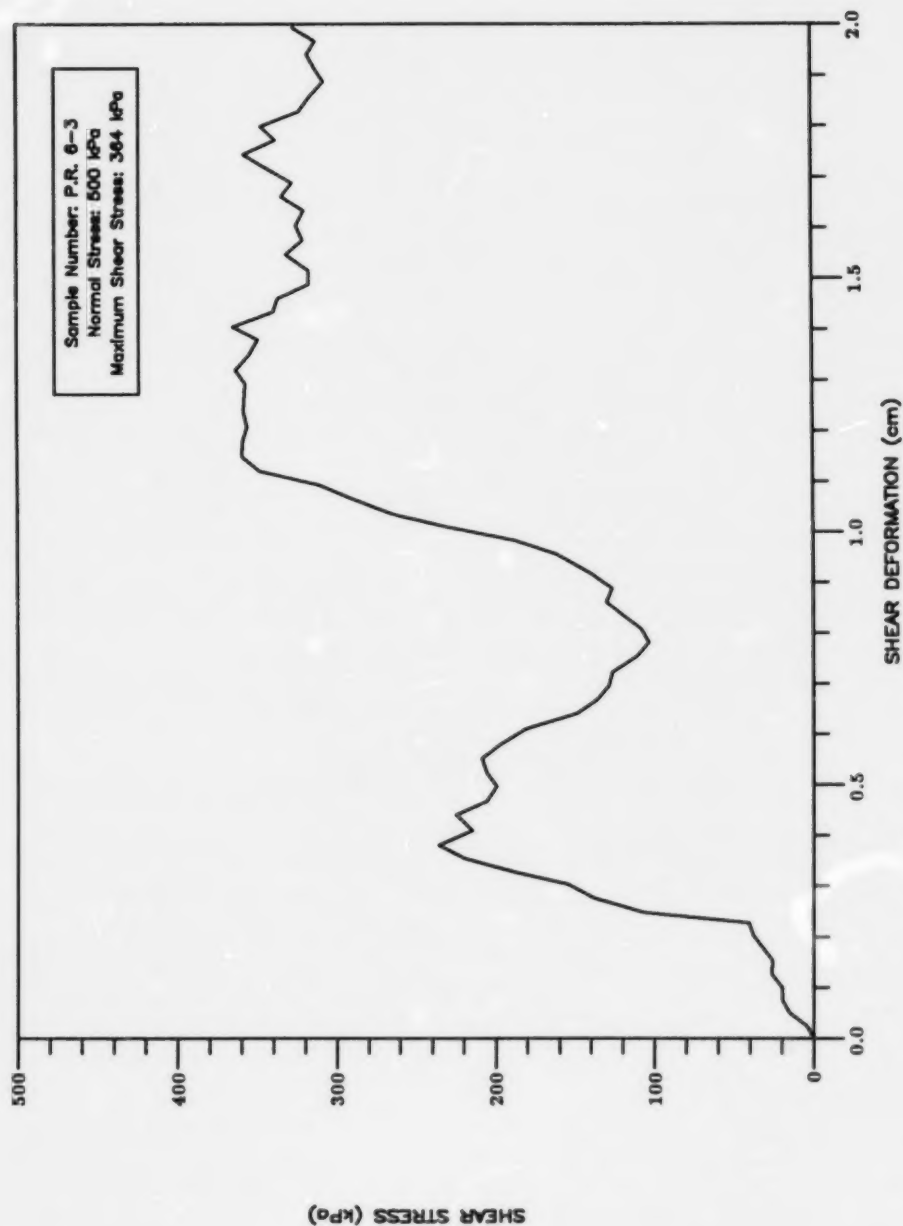
SHEAR STRESS VS DISPLACEMENT: SHEARED PARADISE RIVER SPECIMENS



Note: Direction of shearing was opposite that used for the intact specimen.

FIGURE 15

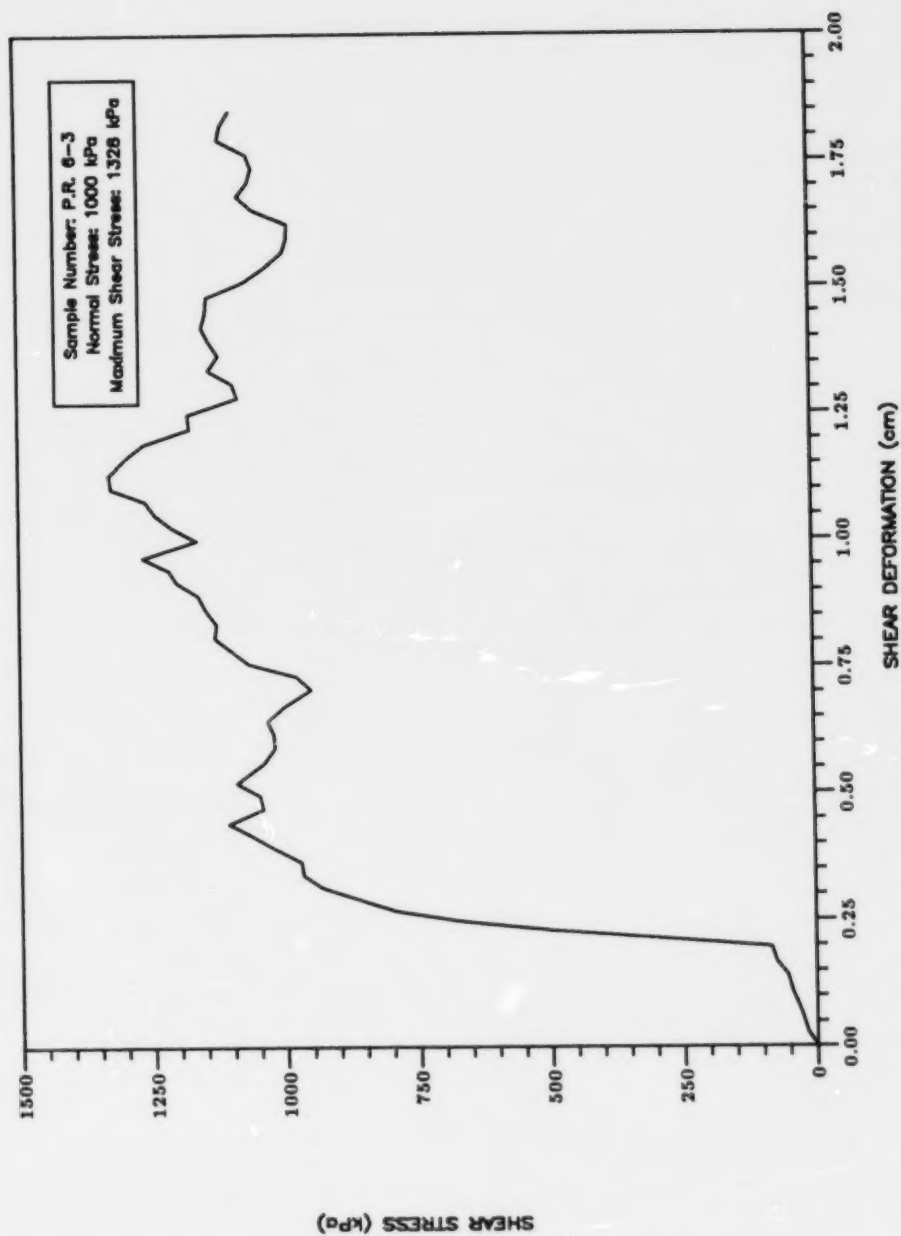
SHEAR STRESS VS DISPLACEMENT: SHEARED PARADISE RIVER SPECIMENS



Note: Direction of shearing was the same as that used for the intact specimen.

FIGURE 16

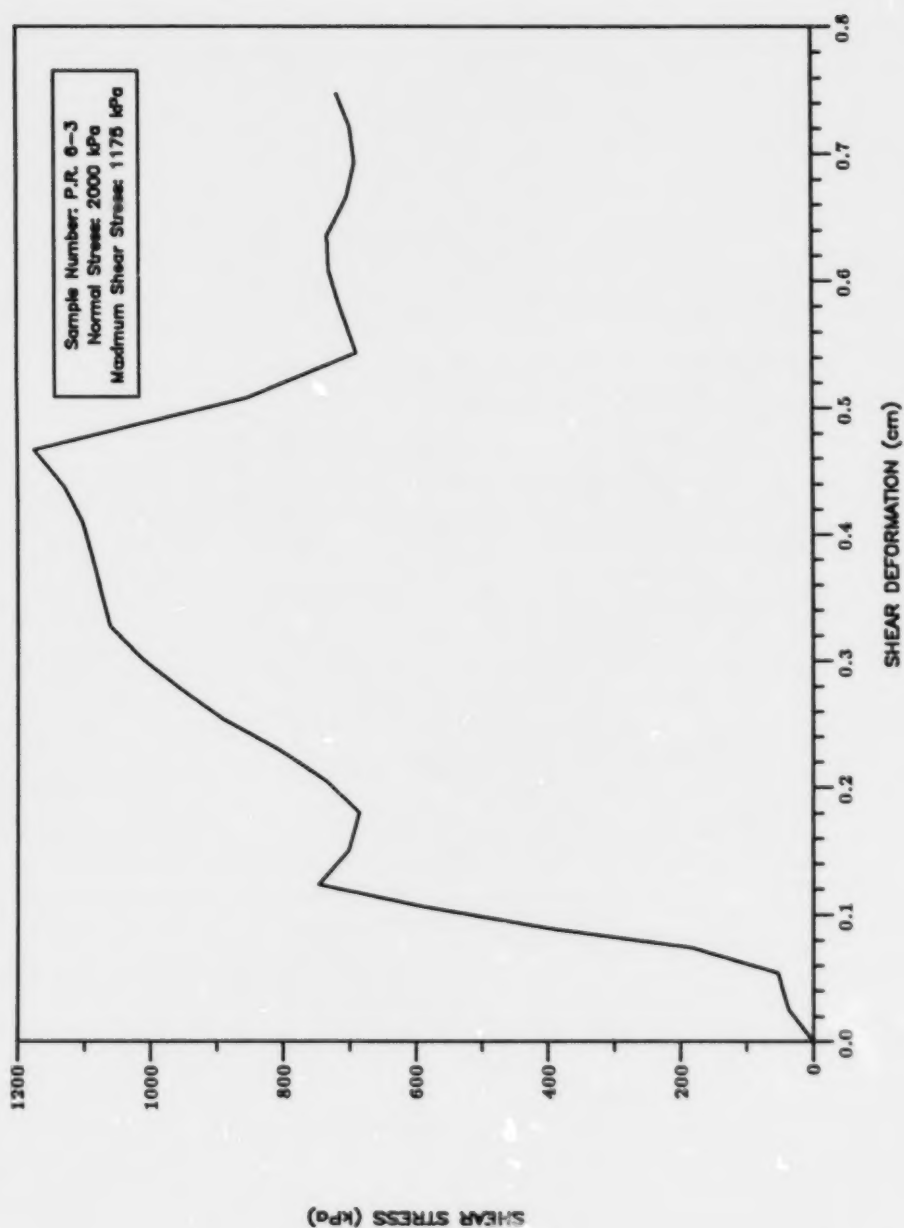
SHEAR STRESS VS DISPLACEMENT: SHEARED PARADISE RIVER SPECIMENS



Note: Direction of shearing was opposite that used for the intact specimen.

FIGURE 17

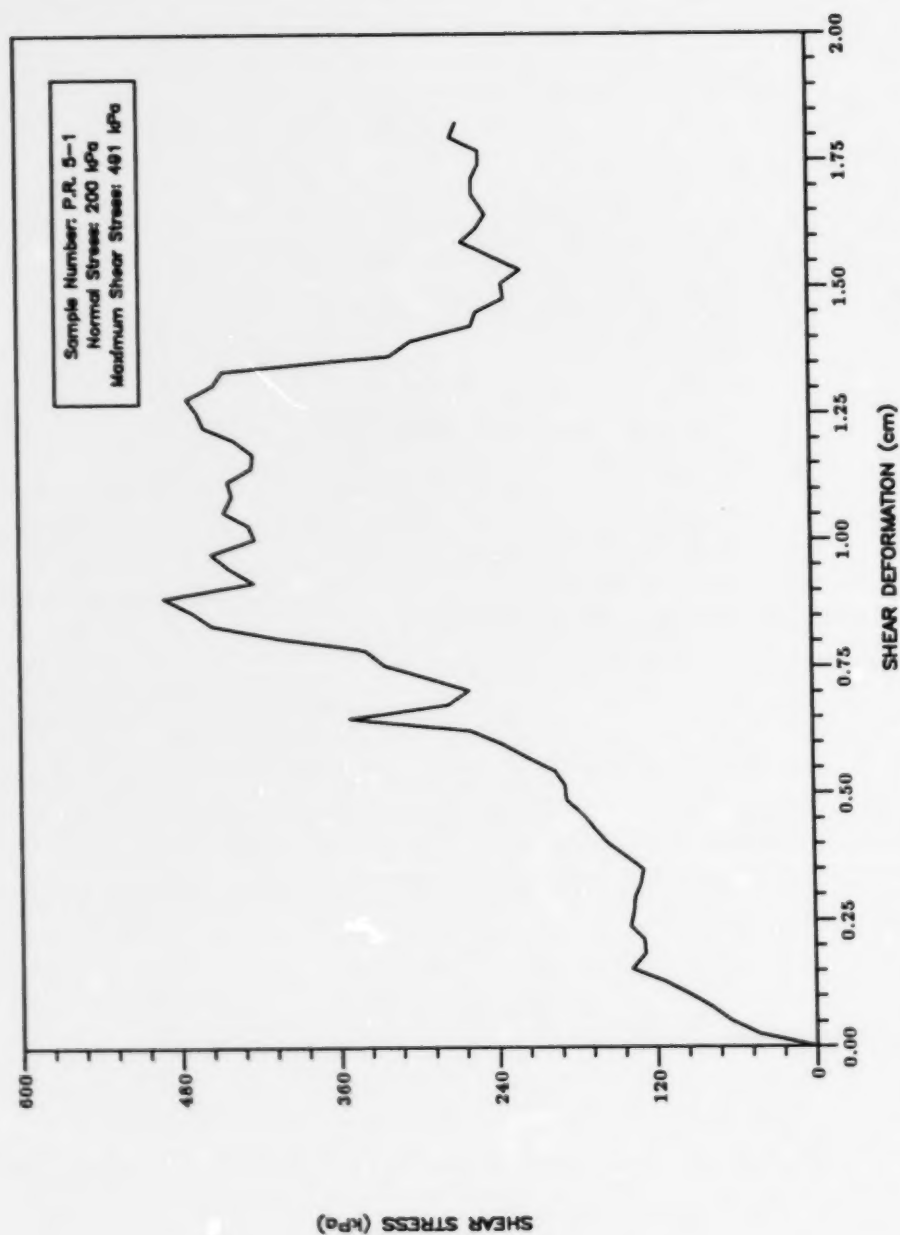
SHEAR STRESS VS DISPLACEMENT: SHEARED PARADISE RIVER SPECIMENS



Note: Direction of shearing was the same as that used for the intact specimen.

FIGURE 18

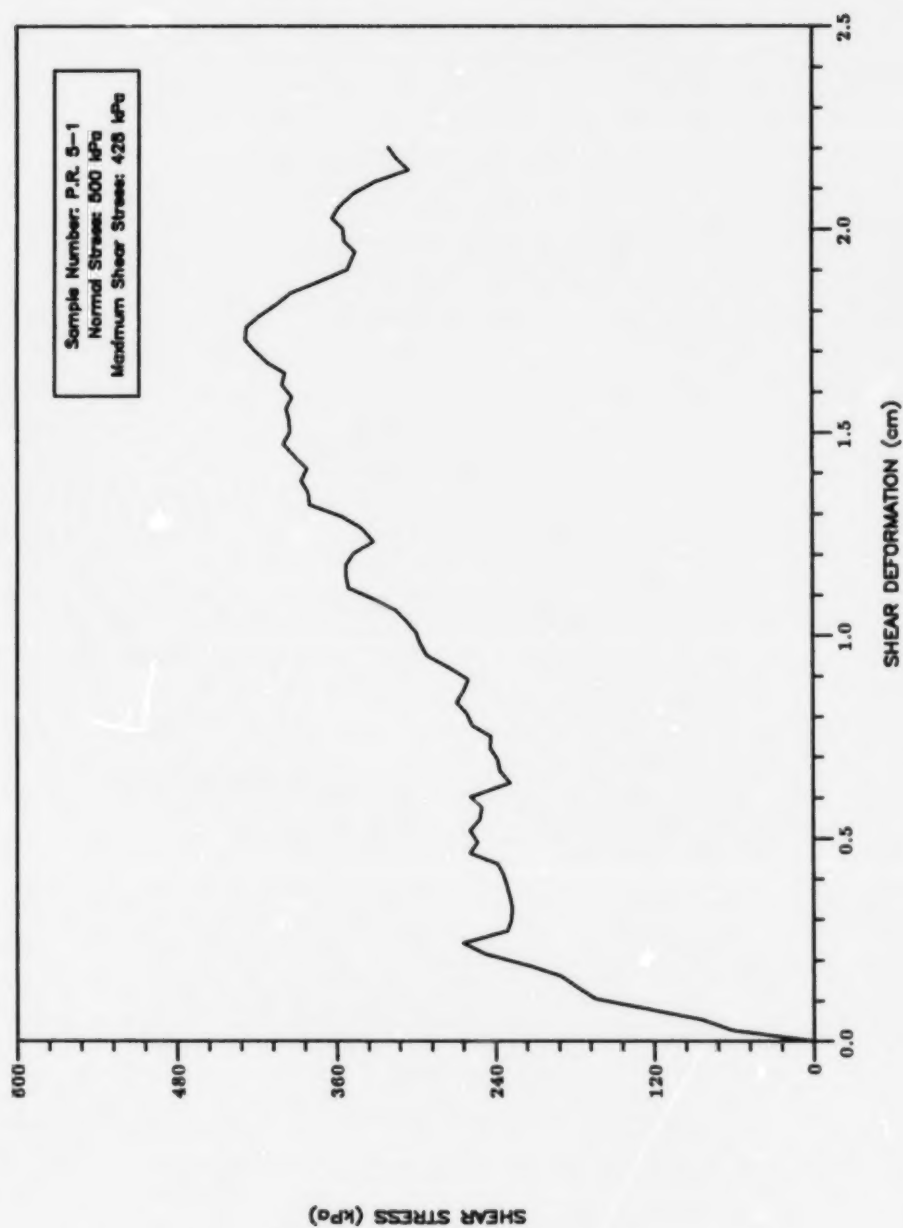
SHEAR STRESS VS DISPLACEMENT: SHEARED PARADISE RIVER SPECIMENS



Note: Direction of shearing was opposite that used for the intact specimen.

FIGURE 19

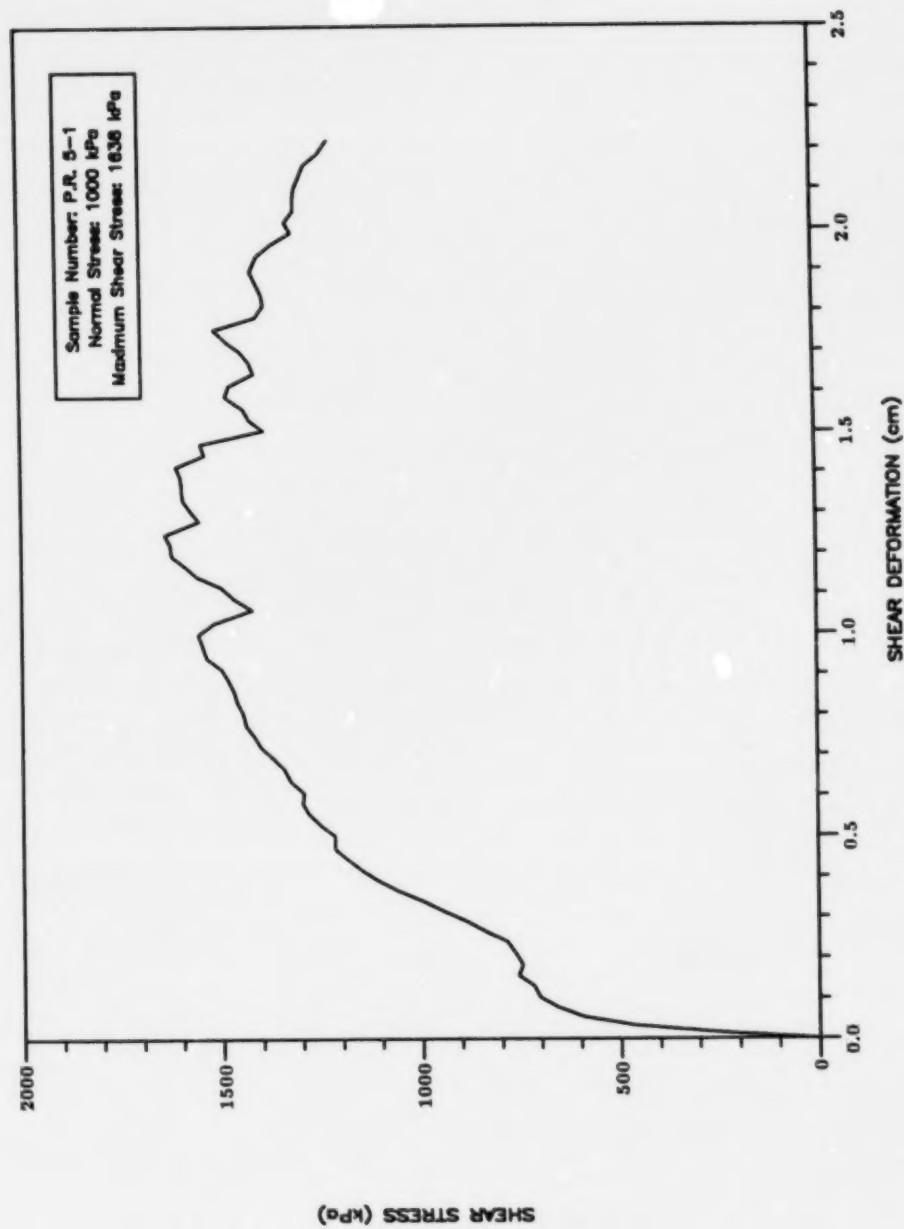
SHEAR STRESS VS DISPLACEMENT: SHEARED PARADISE RIVER SPECIMENS



Note: Direction of shearing was the same as that used for the intact specimen.

FIGURE 20

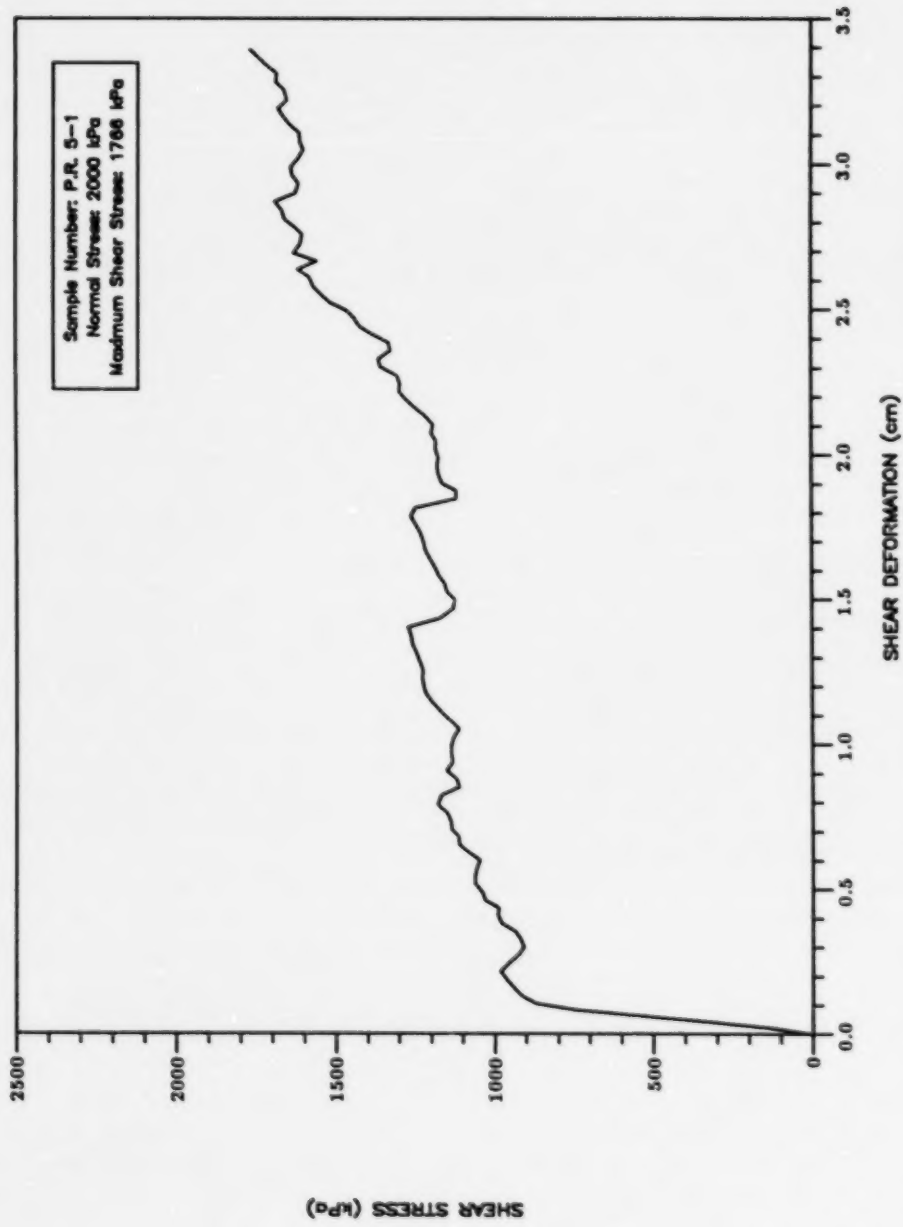
SHEAR STRESS VS DISPLACEMENT: SHEARED PARADISE RIVER SPECIMENS



Note: Direction of shearing was opposite that used for the intact specimen.

FIGURE 21

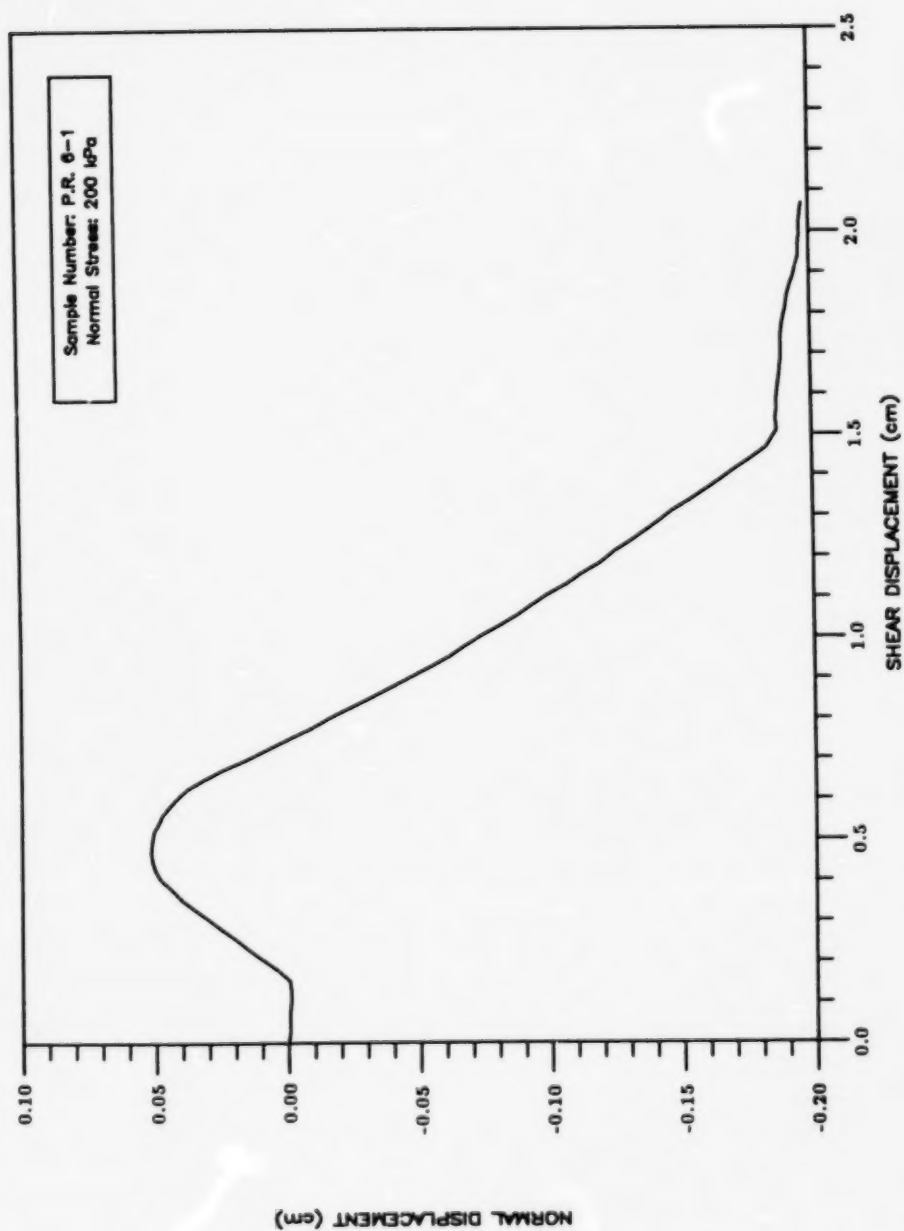
SHEAR STRESS VS DISPLACEMENT: SHEARED PARADISE RIVER SPECIMENS



Note: Direction of shearing was the same as that used for the intact specimen.

FIGURE 22

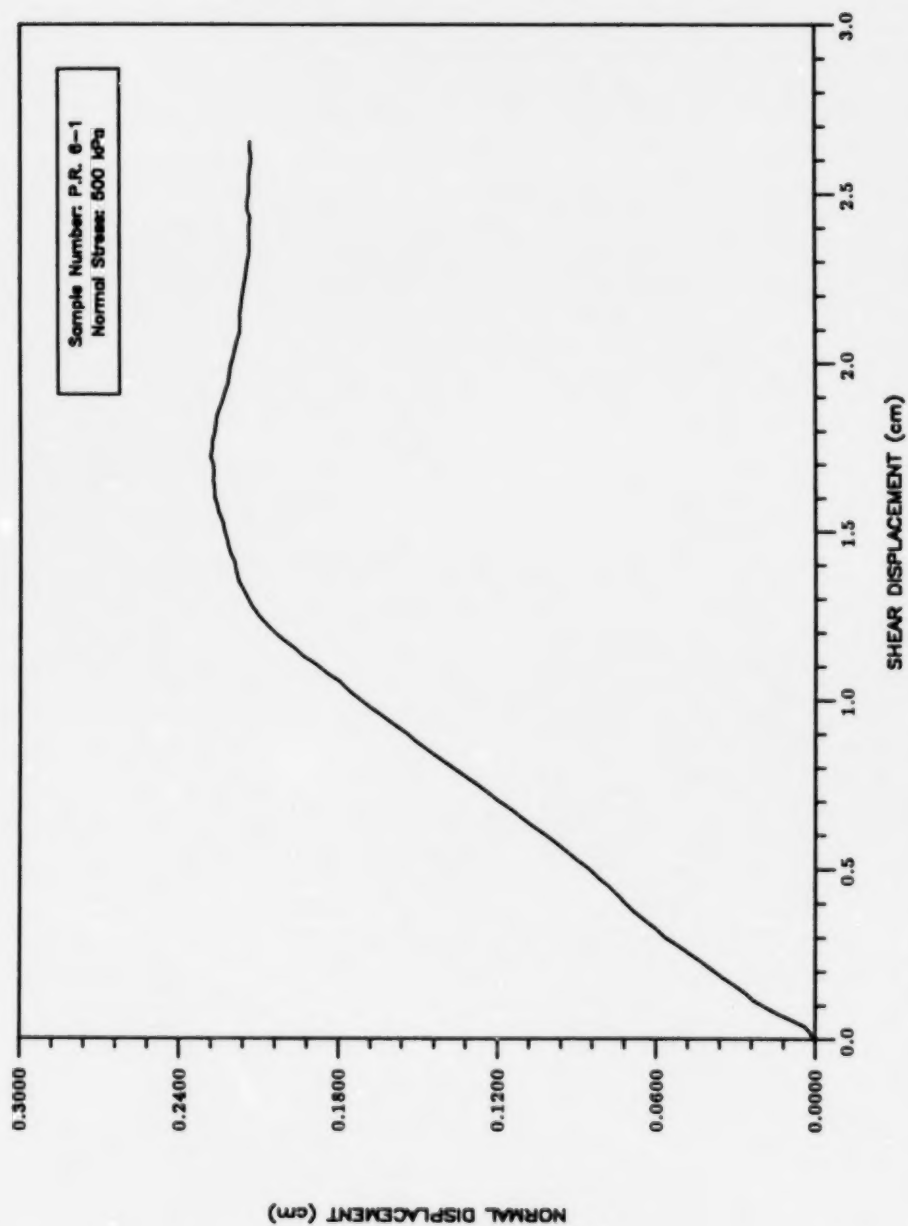
NORMAL VS SHEAR DISPLACEMENT: SHEARED PARADISE RIVER SPECIMENS



Note: Direction of shearing was opposite that used for the intact specimen.

FIGURE 23

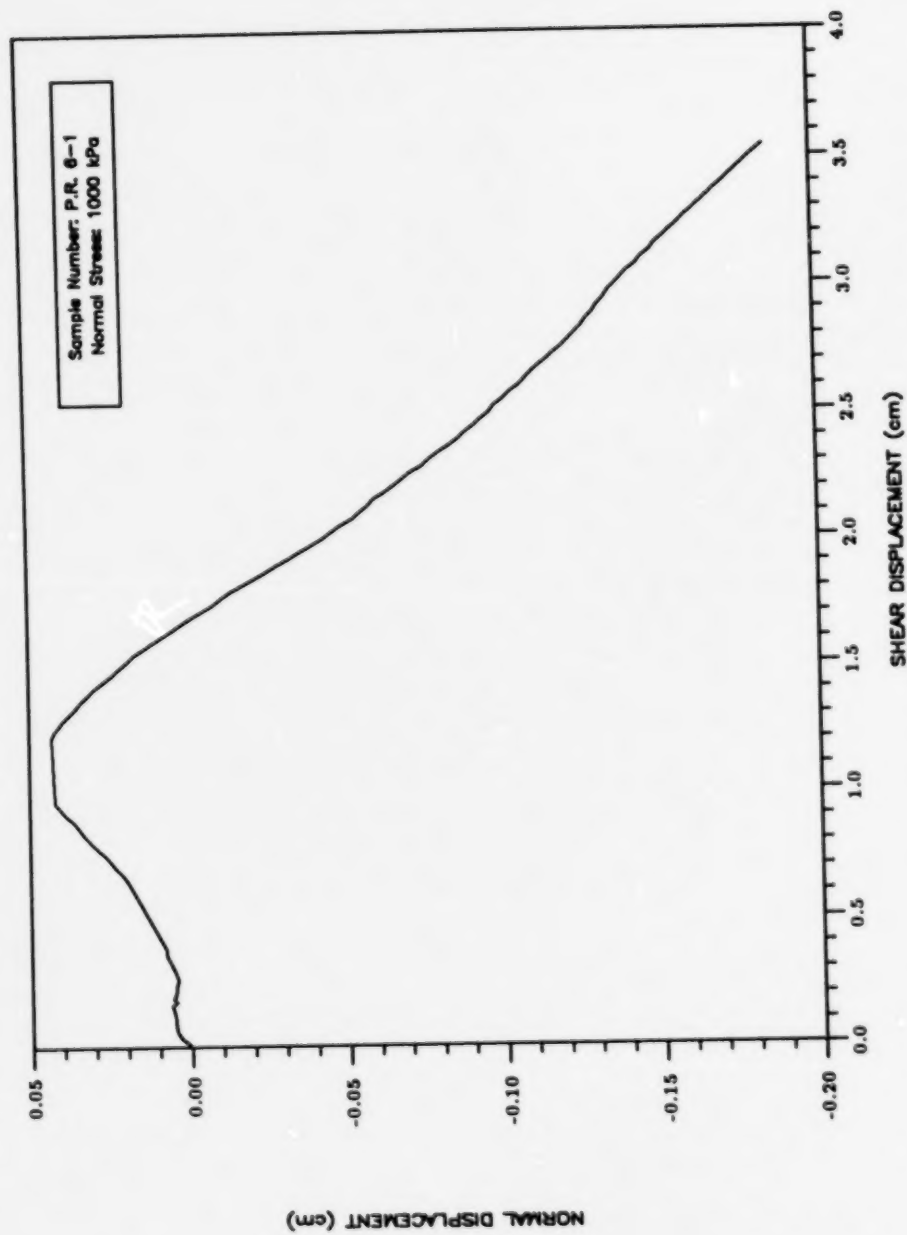
NORMAL VS SHEAR DISPLACEMENT: SHEARED PARADISE RIVER SPECIMENS



Note: Direction of shearing was the same as that used for the intact specimen.

FIGURE 24

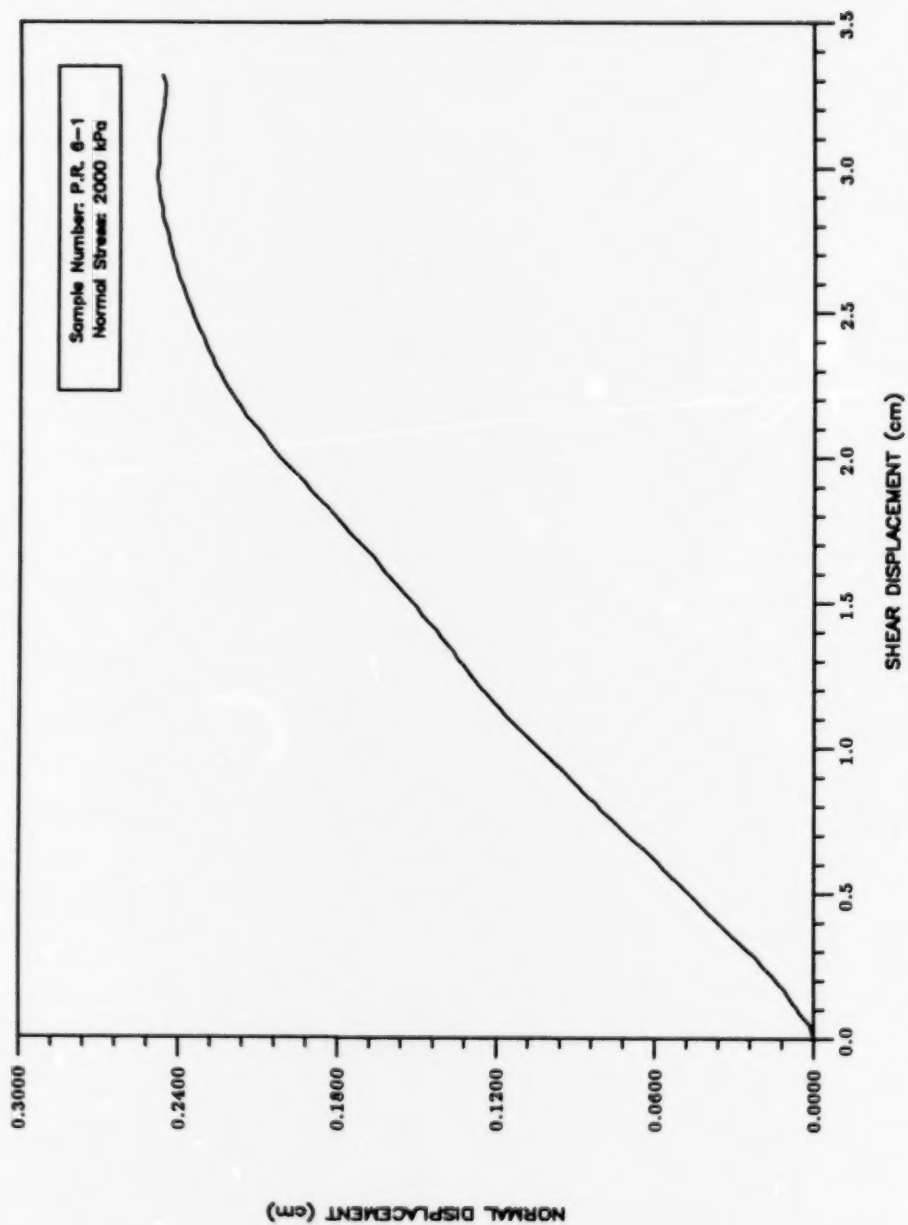
NORMAL VS SHEAR DISPLACEMENT: SHEARED PARADISE RIVER SPECIMENS



Note: Direction of shearing was opposite that used for the intact specimen.

FIGURE 25

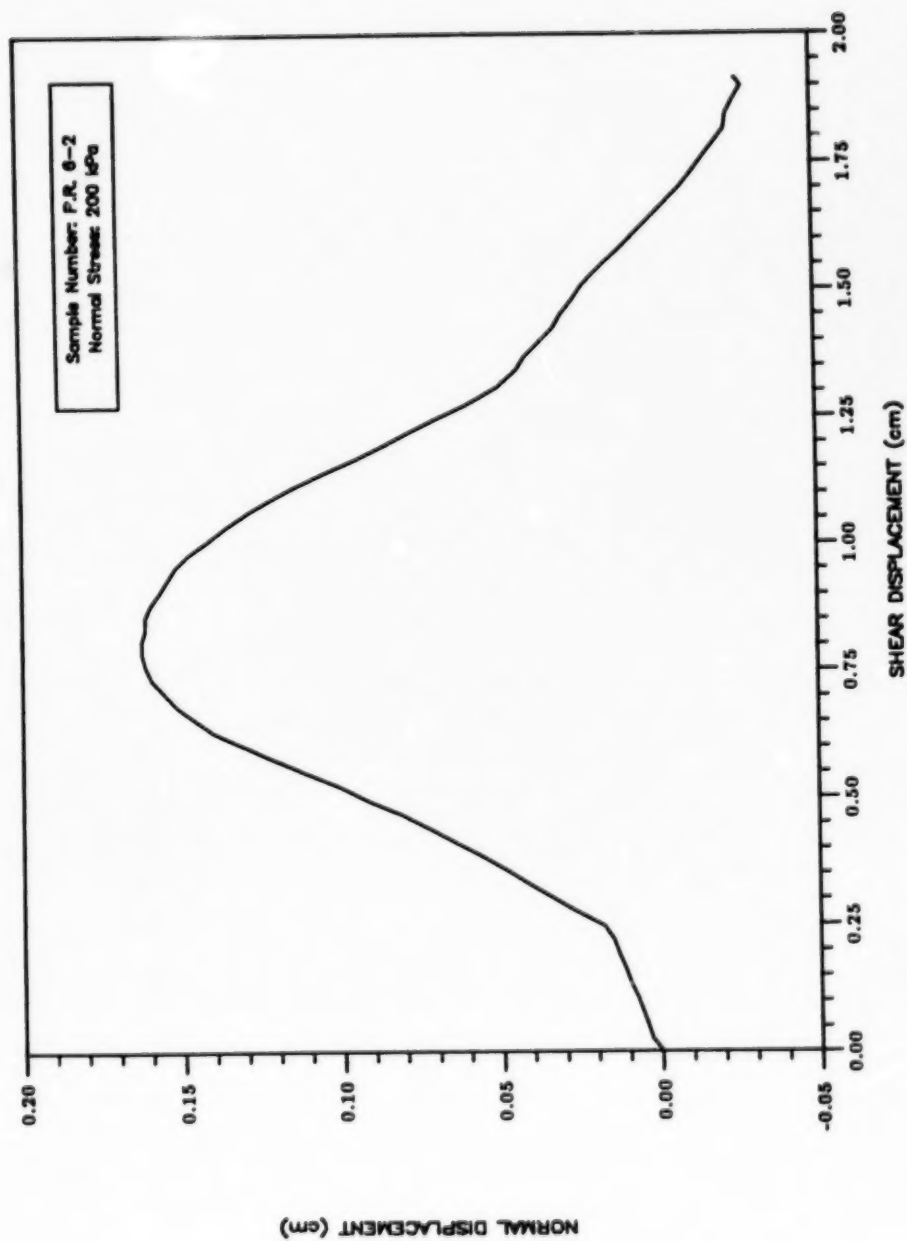
NORMAL VS SHEAR DISPLACEMENT: SHEARED PARADISE RIVER SPECIMENS



Note: Direction of shearing was the same as that used for the intact specimen.

FIGURE 26

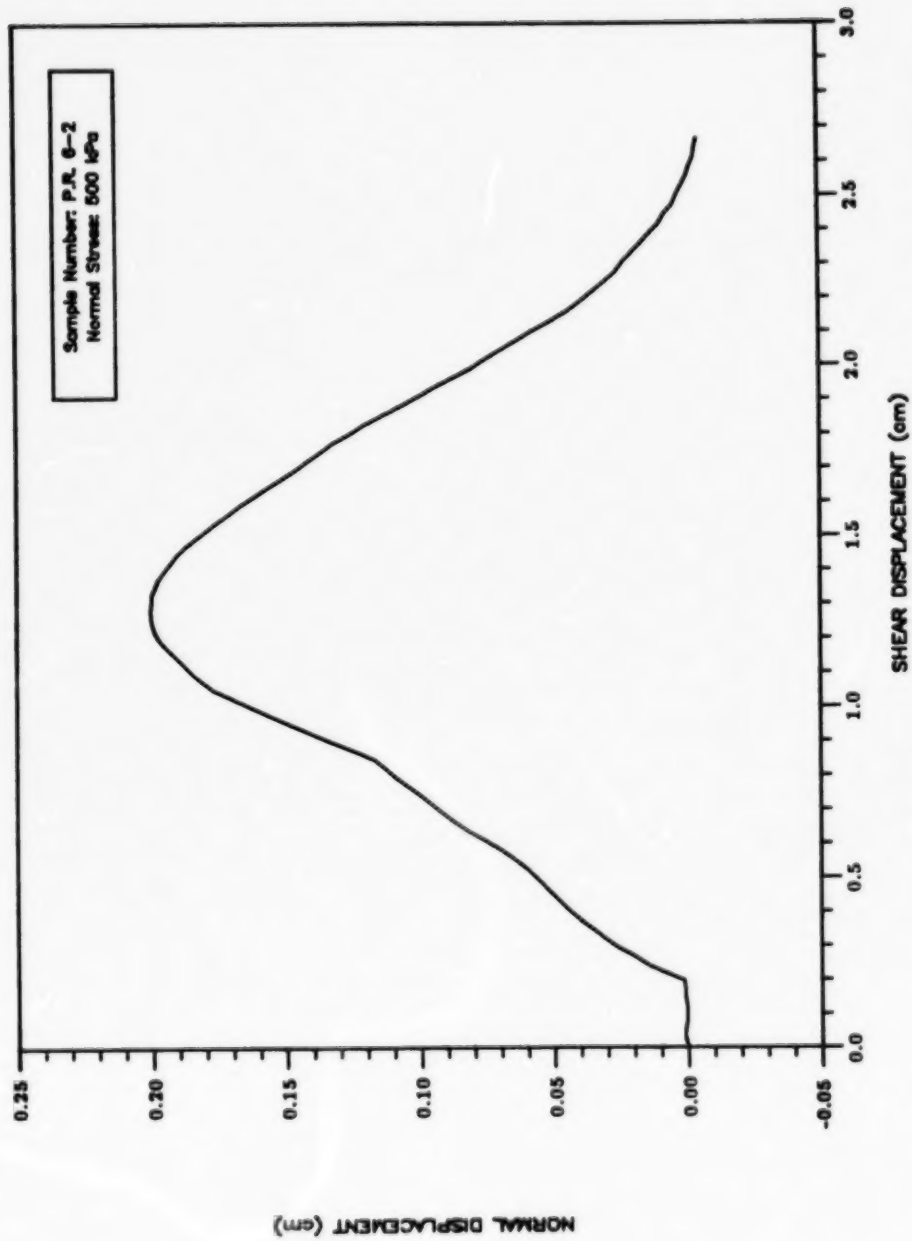
NORMAL VS SHEAR DISPLACEMENT: SHEARED PARADISE RIVER SPECIMENS



Note: Direction of shearing was opposite that used for the intact specimen.

FIGURE 27

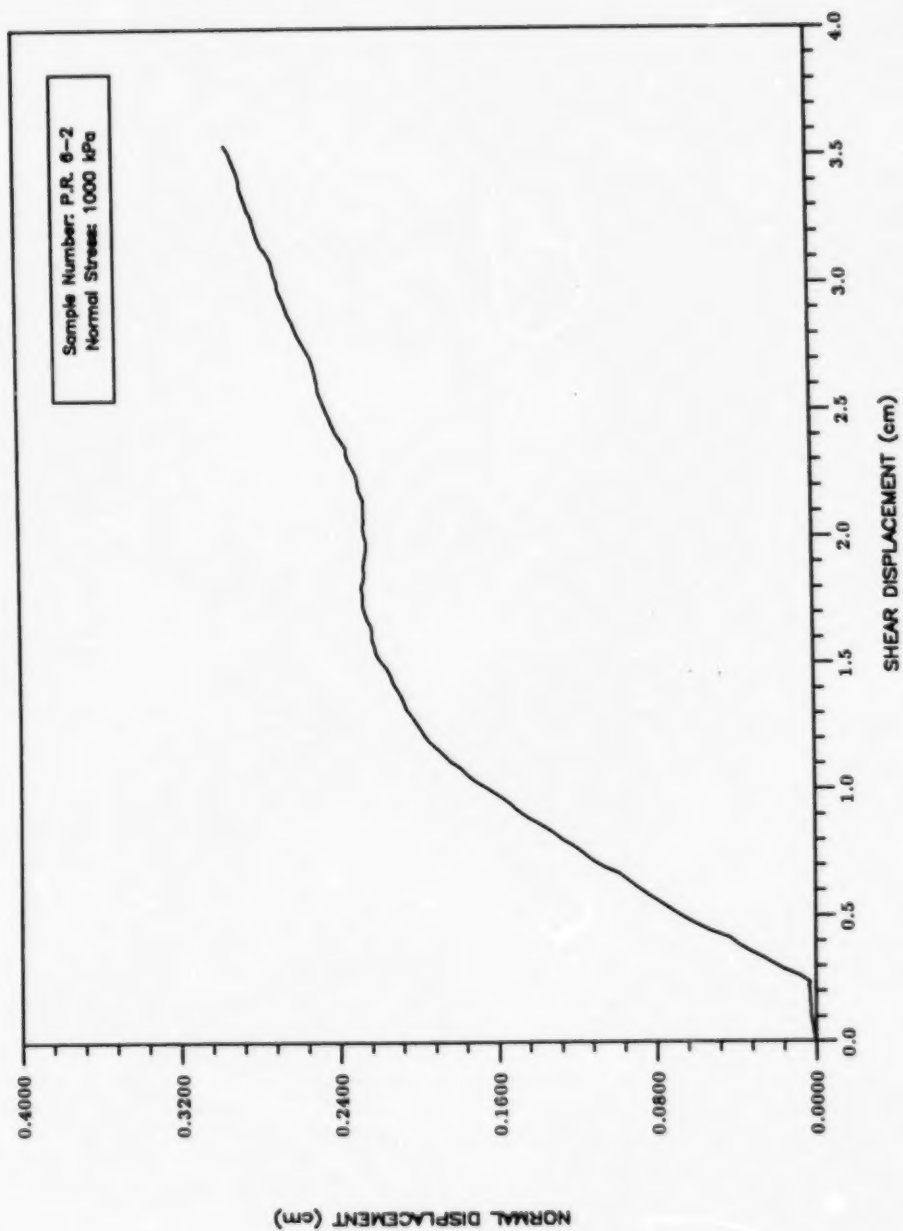
NORMAL VS SHEAR DISPLACEMENT: SHEARED PARADISE RIVER SPECIMENS



Note: Direction of shearing was the same as that used for the intact specimen.

FIGURE 28

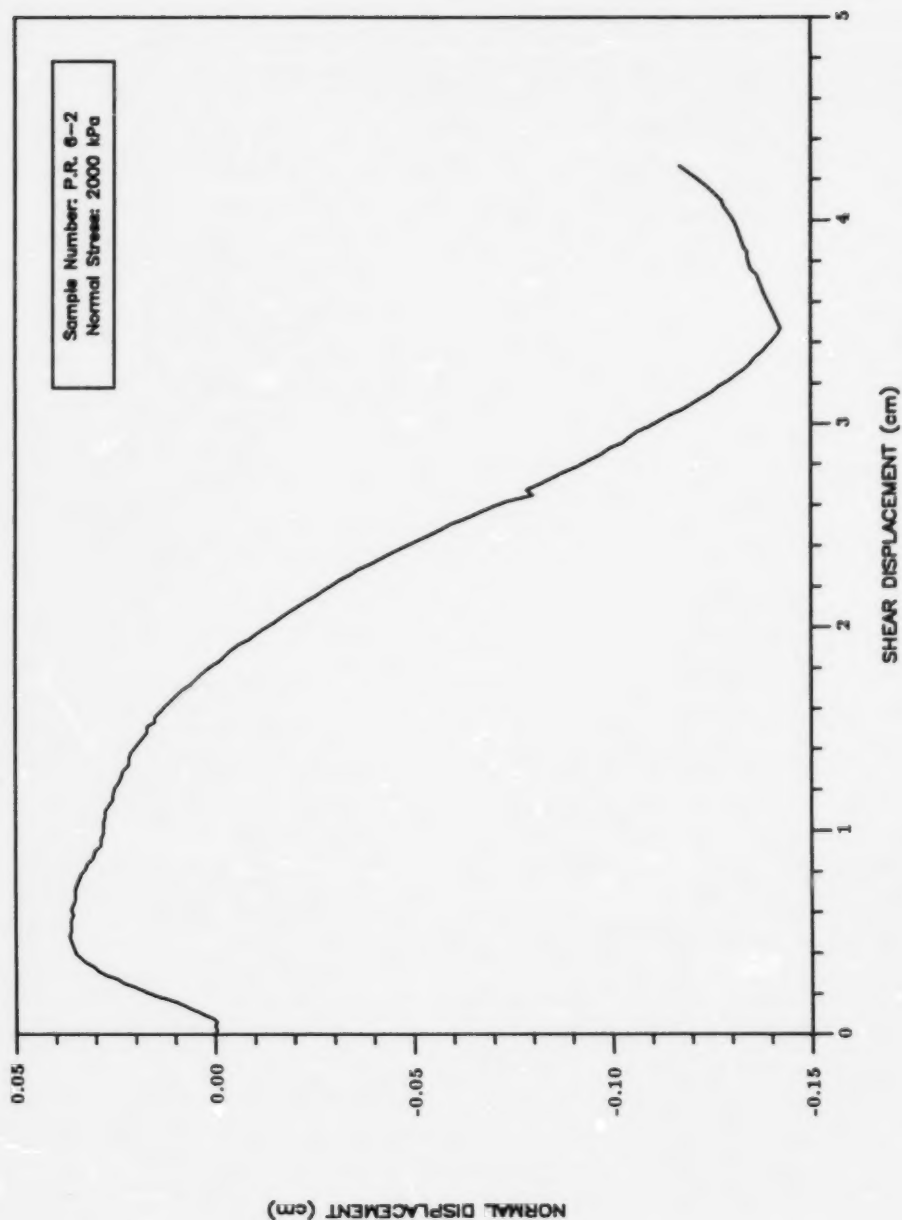
NORMAL VS SHEAR DISPLACEMENT: SHEARED PARADISE RIVER SPECIMENS



Note: Direction of shearing was opposite that used for the intact specimen.

FIGURE 29

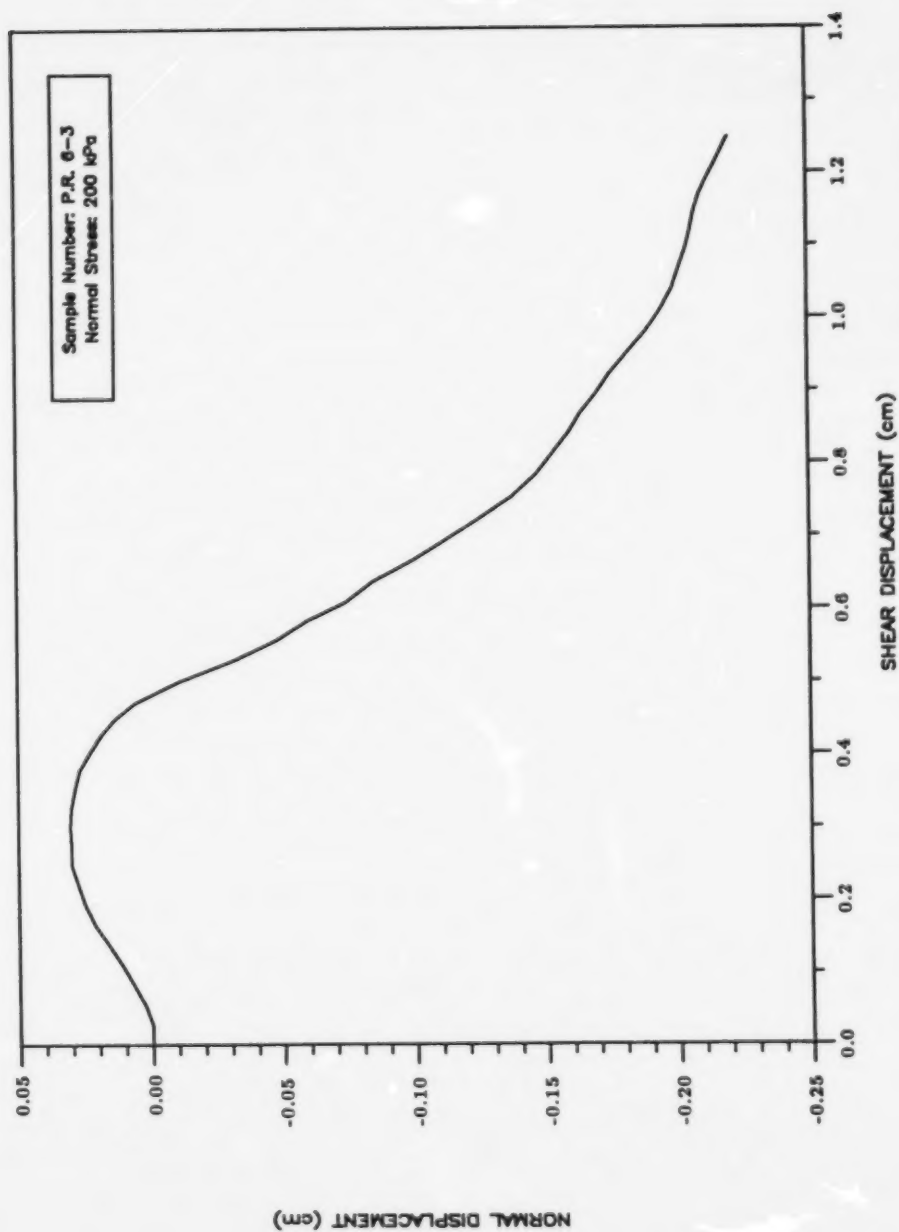
NORMAL VS SHEAR DISPLACEMENT: SHEARED PARADISE RIVER SPECIMENS



Note: Direction of shearing was the same as that used for the intact specimen.

FIGURE 30

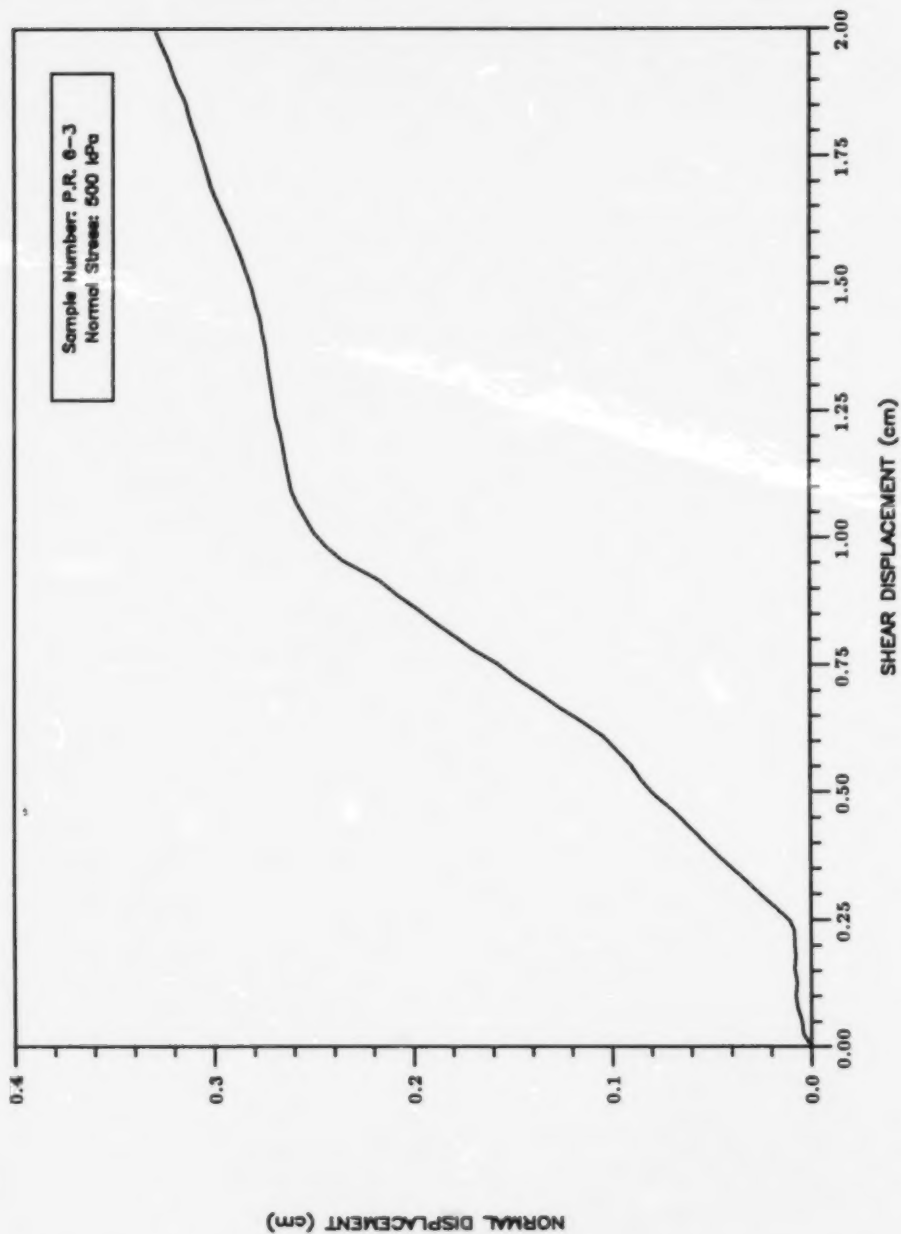
NORMAL VS SHEAR DISPLACEMENT: SHEARED PARADISE RIVER SPECIMENS



Note: Direction of shearing was opposite that used for the intact specimen.

FIGURE 31

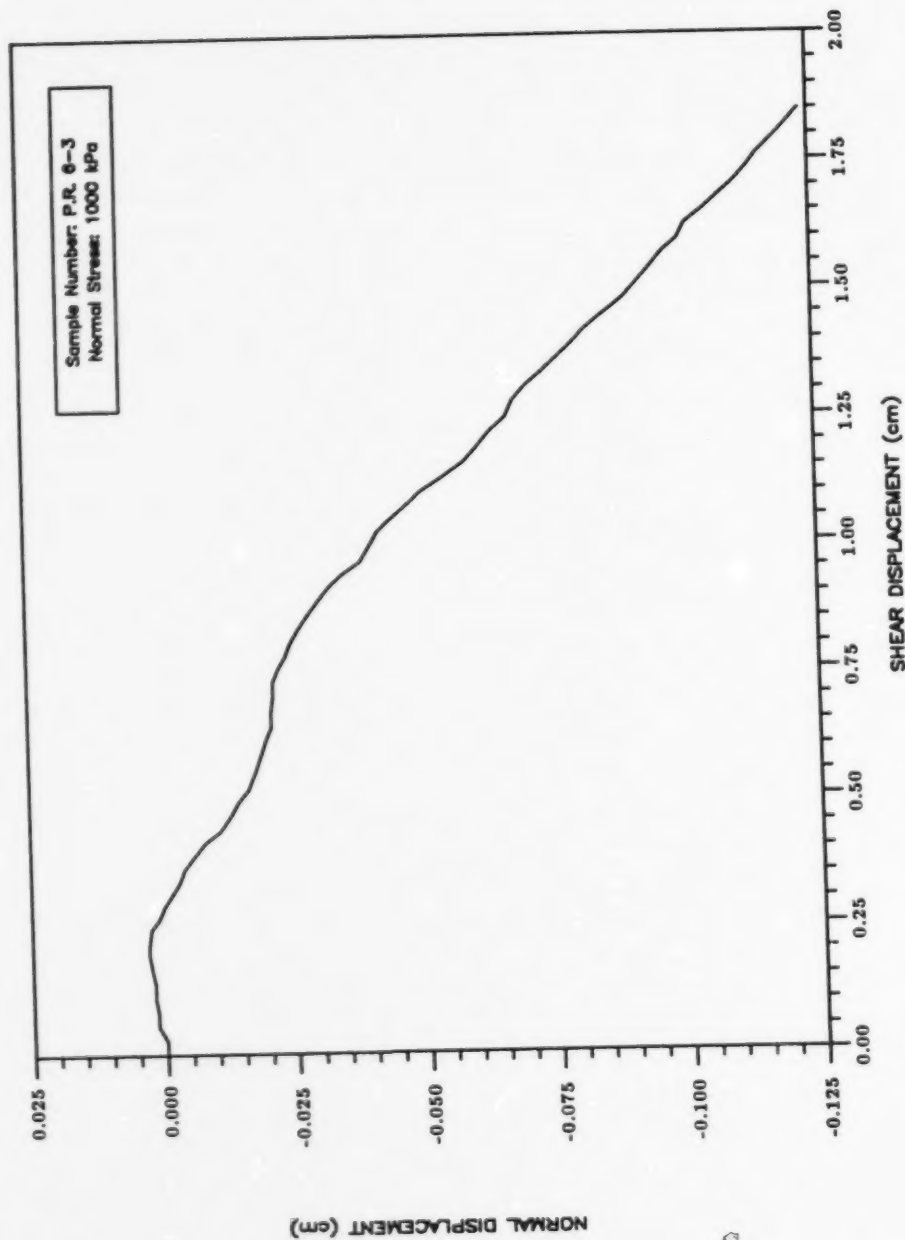
NORMAL VS SHEAR DISPLACEMENT: SHEARED PARADISE RIVER SPECIMENS



Note: Direction of shearing was the same as that used for the intact specimen.

FIGURE 32

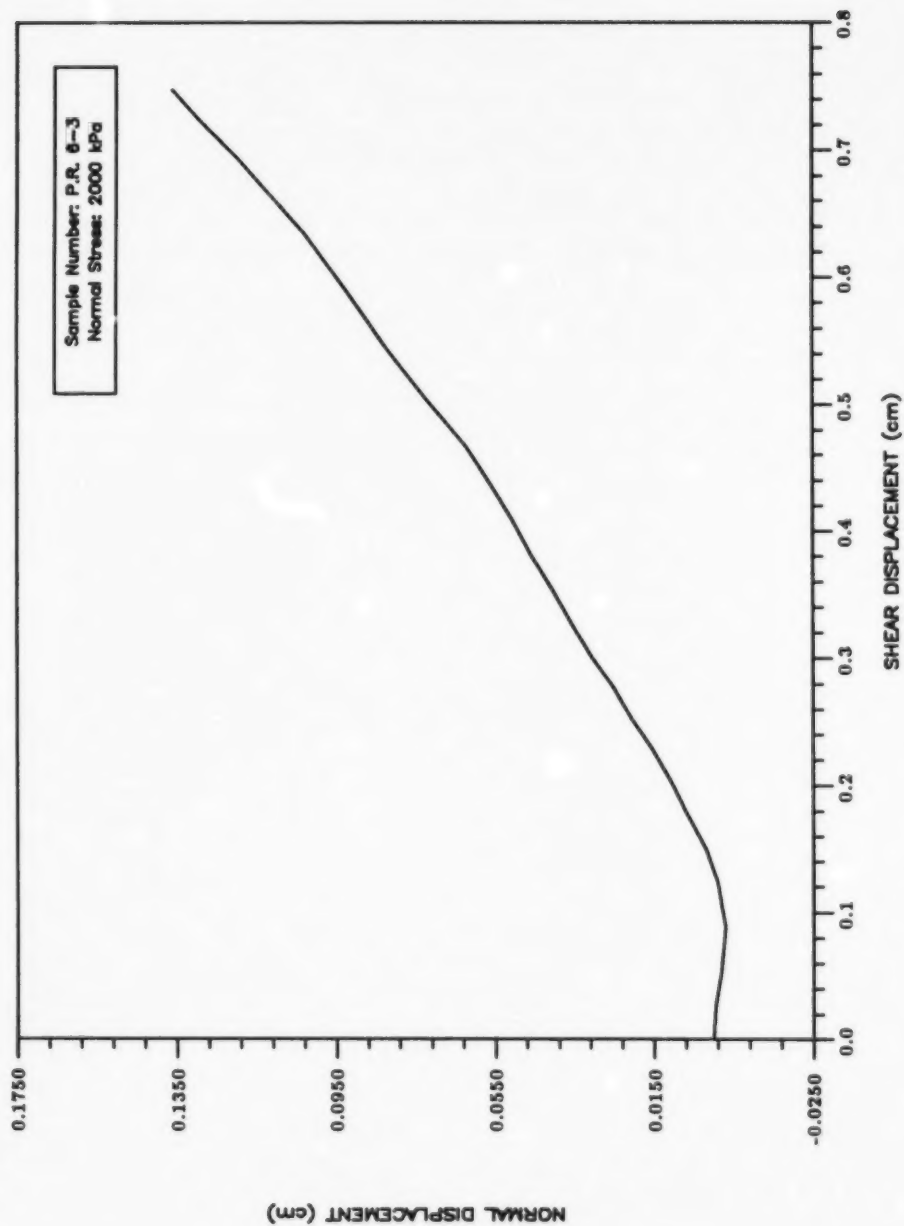
NORMAL VS SHEAR DISPLACEMENT: SHEARED PARADISE RIVER SPECIMENS



Note: Direction of shearing was opposite that used for the intact specimen.

FIGURE 33

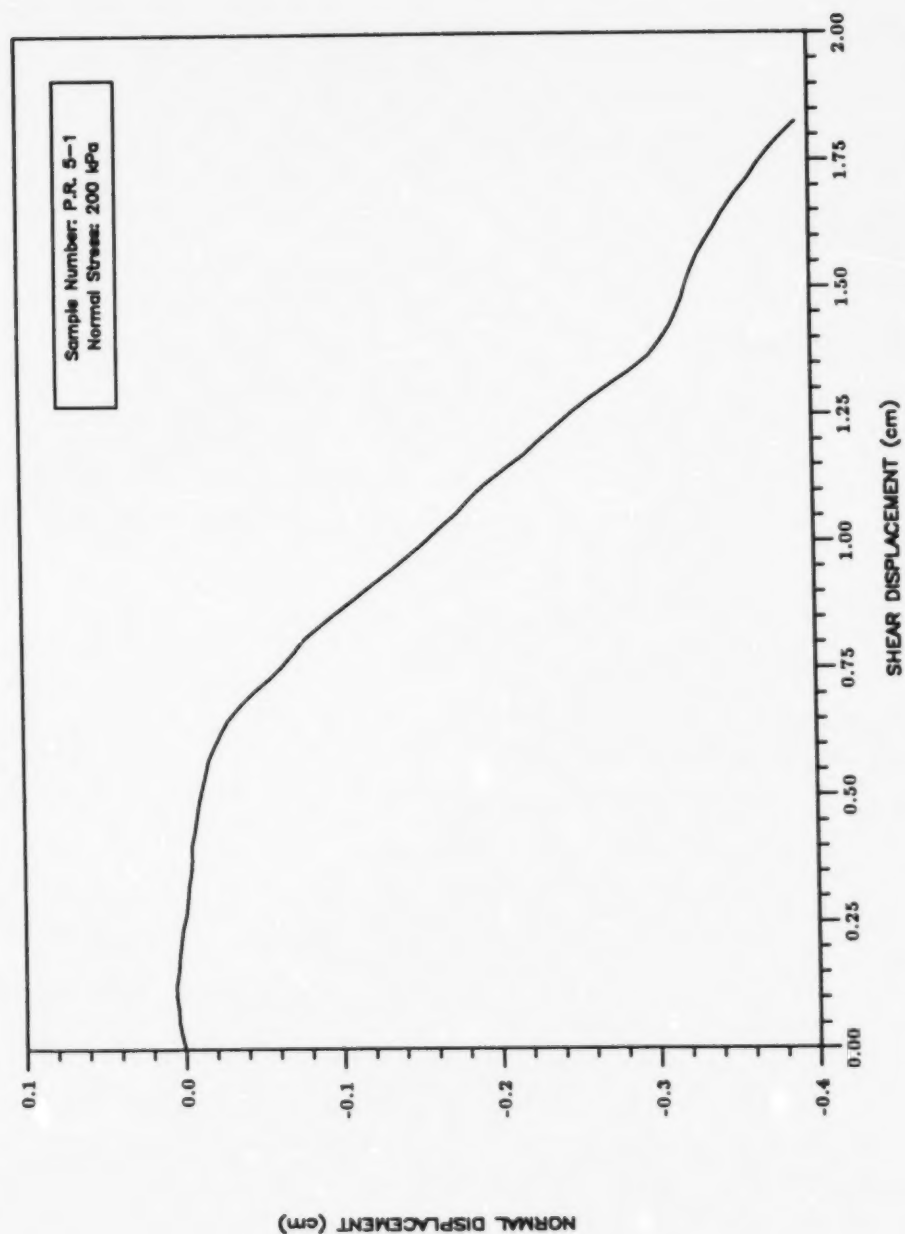
NORMAL VS SHEAR DISPLACEMENT: SHEARED PARADISE RIVER SPECIMENS



Note: Direction of shearing was the same as that used for the intact specimen.

FIGURE 34

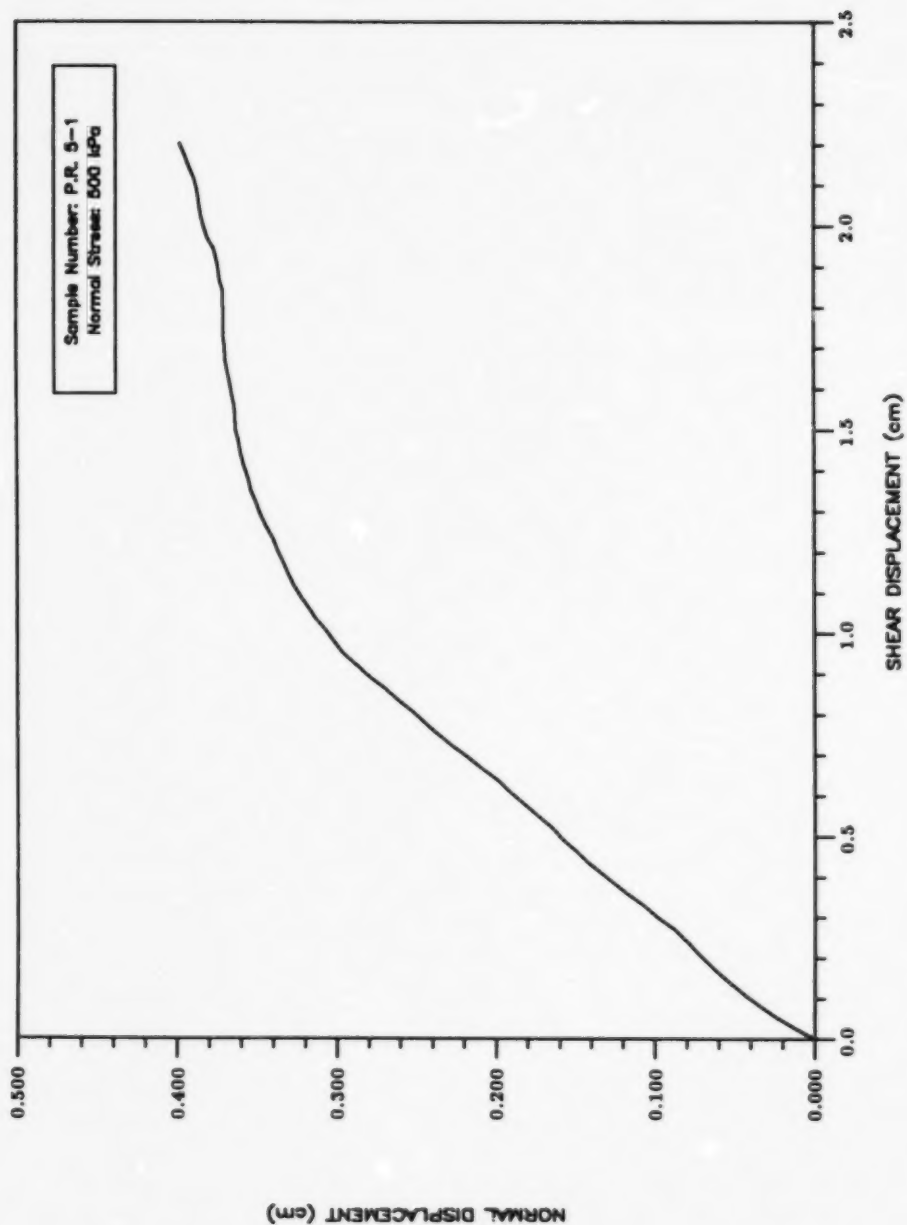
NORMAL VS SHEAR DISPLACEMENT: SHEARED PARADISE RIVER SPECIMENS



Note: Direction of shearing was opposite that used for the intact specimen.

FIGURE 35

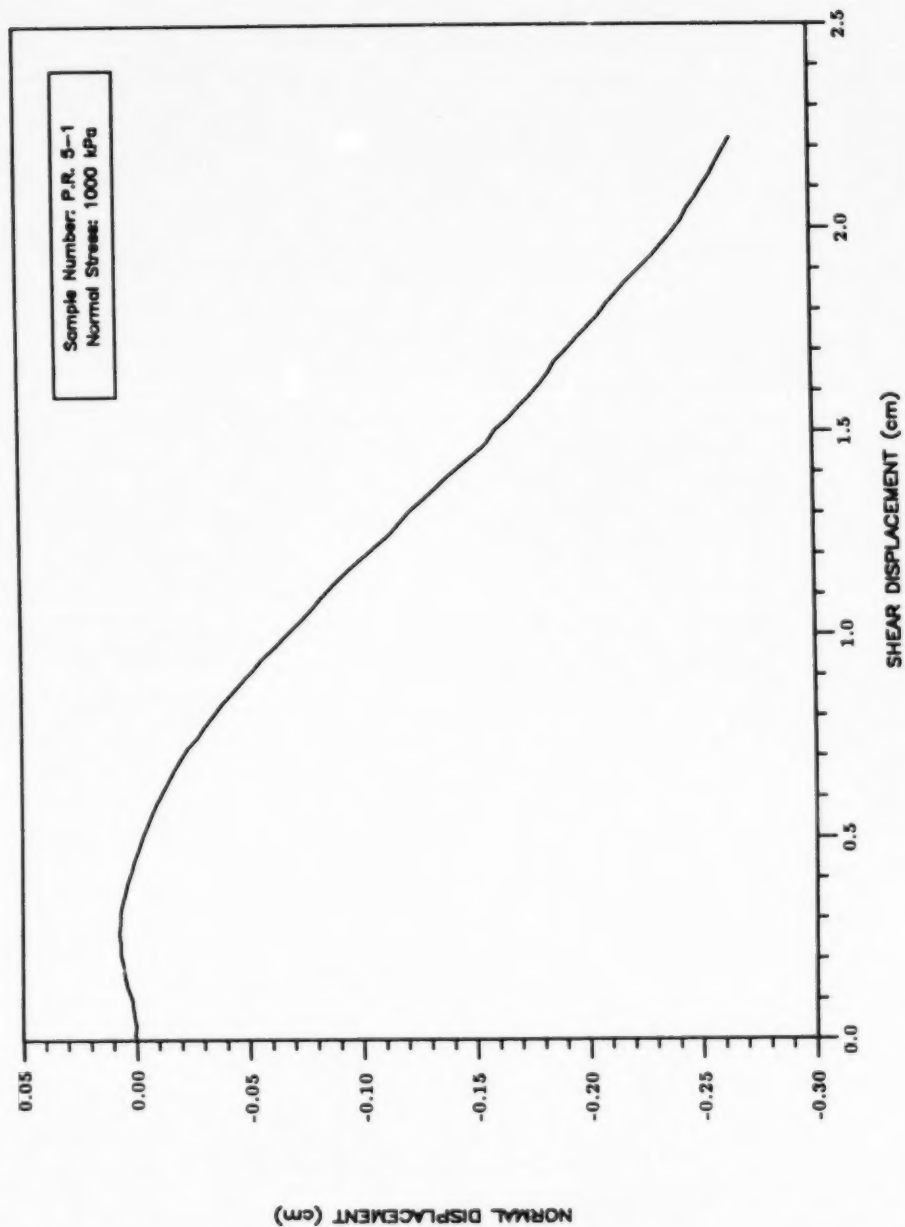
NORMAL VS SHEAR DISPLACEMENT: SHEARED PARADISE RIVER SPECIMENS



Note: Direction of shearing was the same as that used for the intact specimen.

FIGURE 36

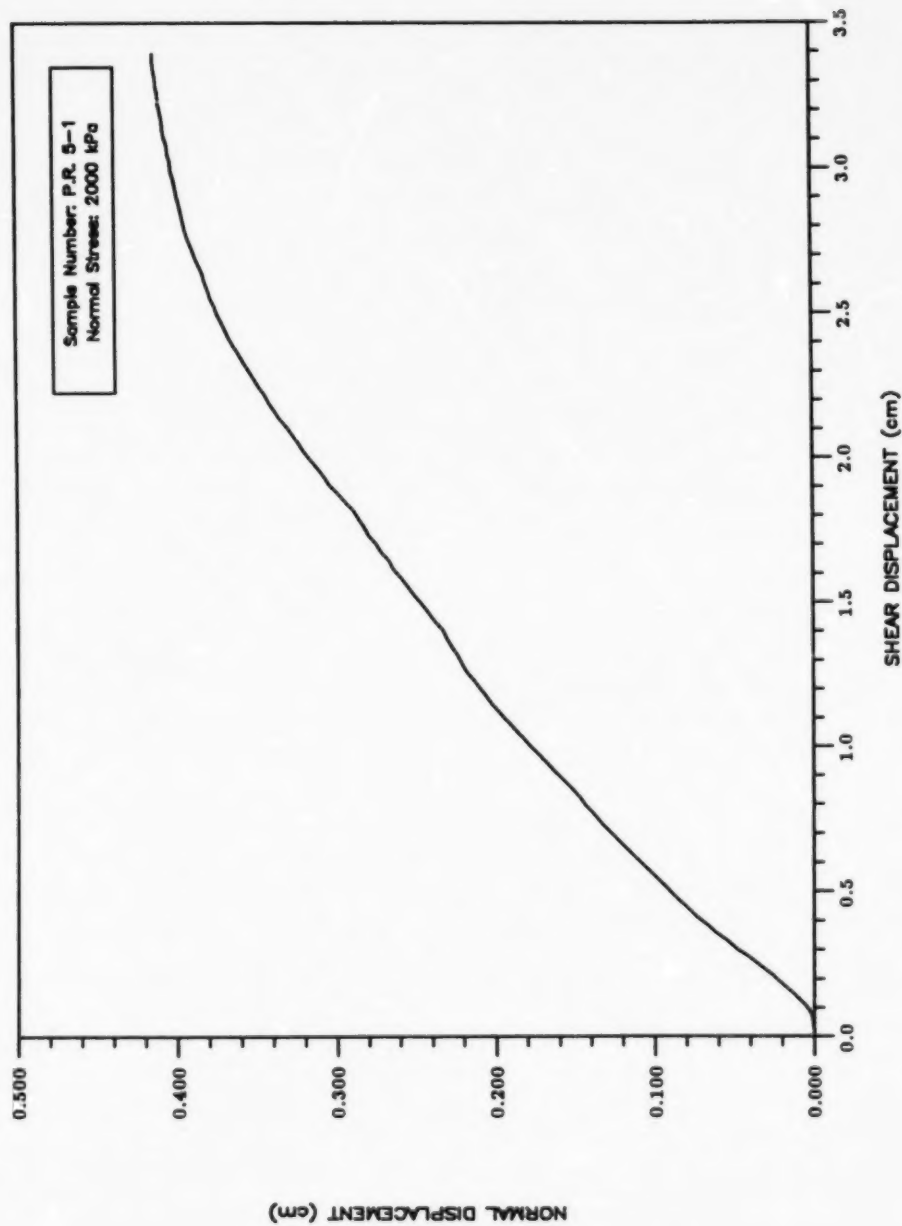
NORMAL VS SHEAR DISPLACEMENT: SHEARED PARADISE RIVER SPECIMENS



Note: Direction of shearing was opposite that used for the intact specimen.

FIGURE 37

NORMAL VS SHEAR DISPLACEMENT: SHEARED PARADISE RIVER SPECIMENS



Note: Direction of shearing was the same as that used for the intact specimen.

FIGURE 38

SHEAR STRESS VS NORMAL STRESS: INTACT PARADISE RIVER SPECIMENS

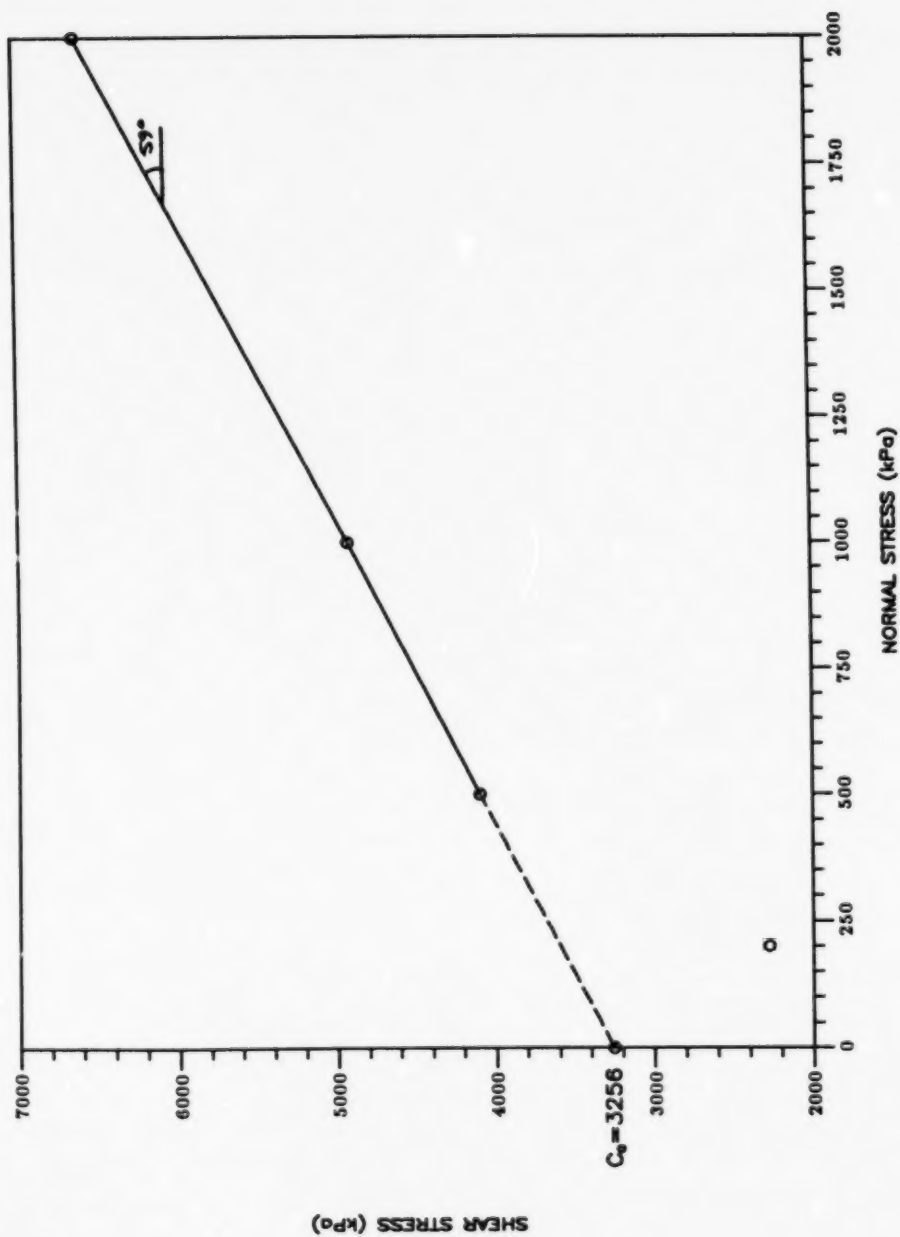


FIGURE 39

RESIDUAL SHEAR STRESS VS NORMAL STRESS FOR PARADISE RIVER SPECIMENS

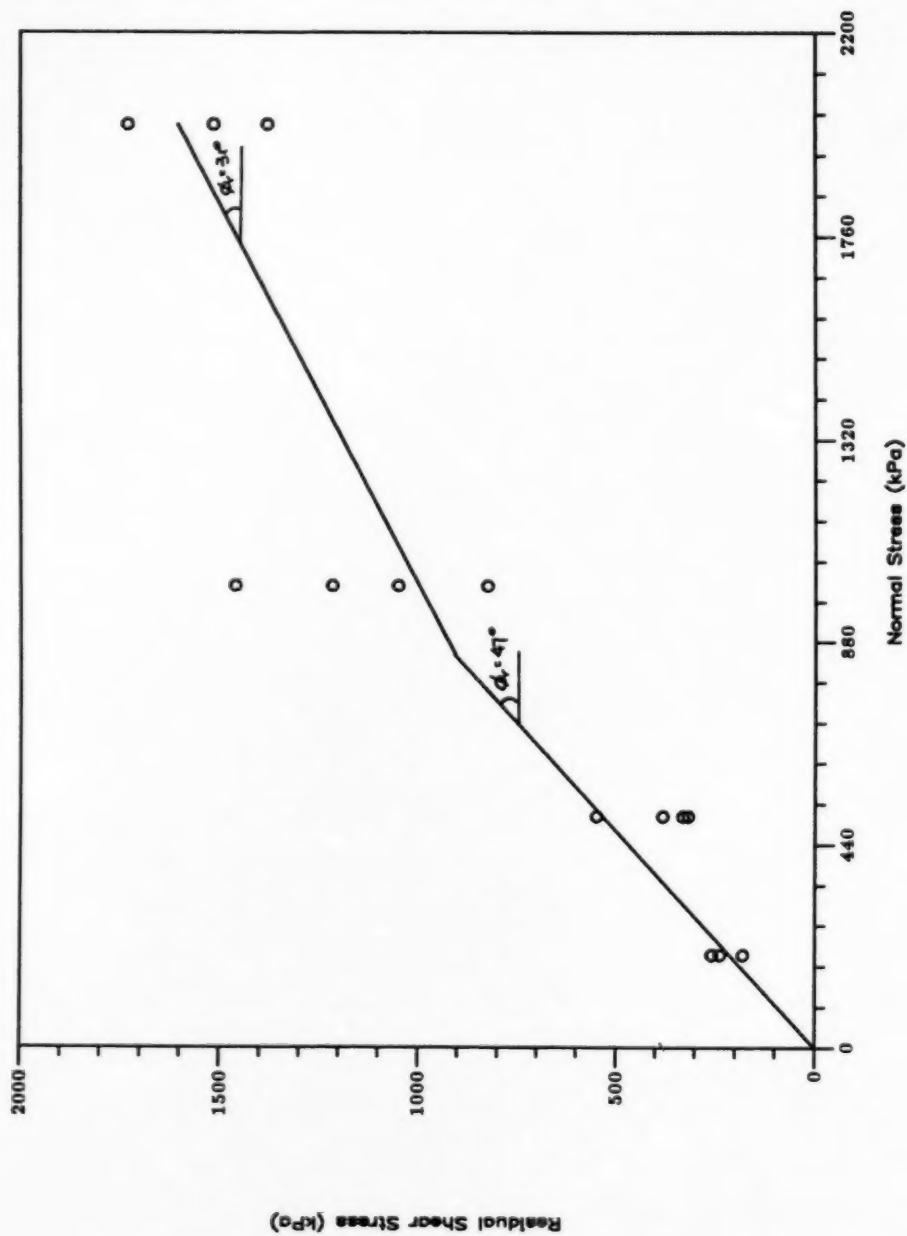
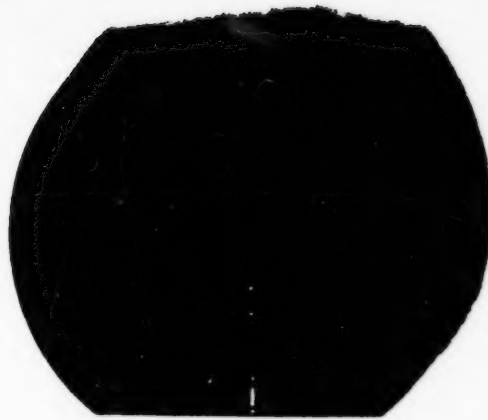


FIGURE 40



SAMPLE LN 0071-1

1

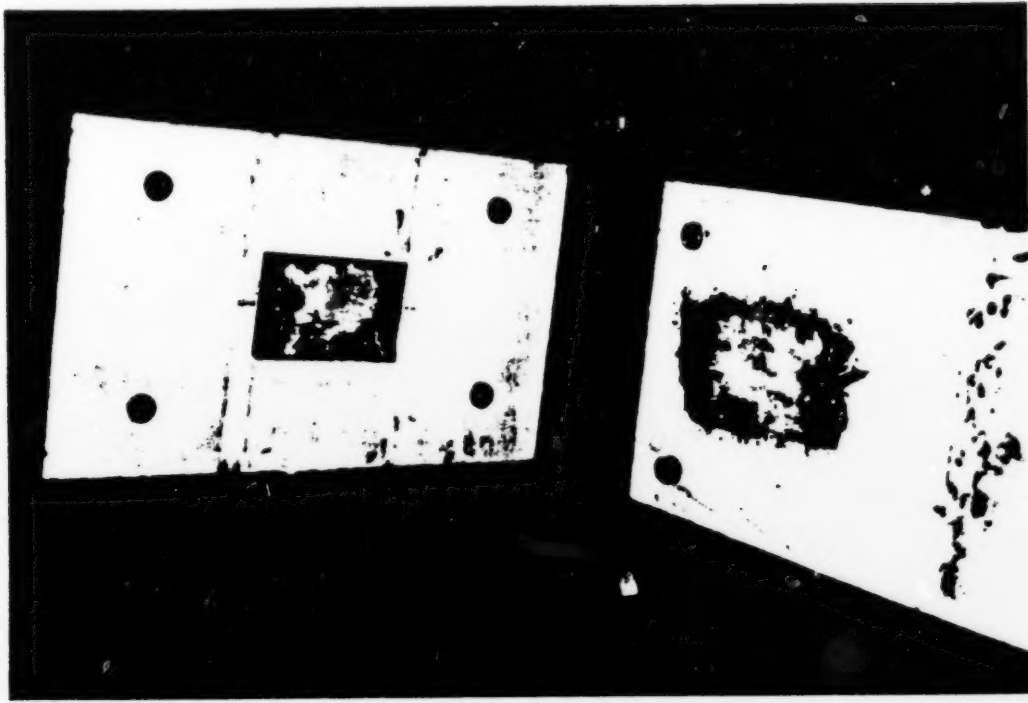


Figure 41: Sample No. PR 6-1 Before and After Shearing



SAMPLE NO. PR 6-2

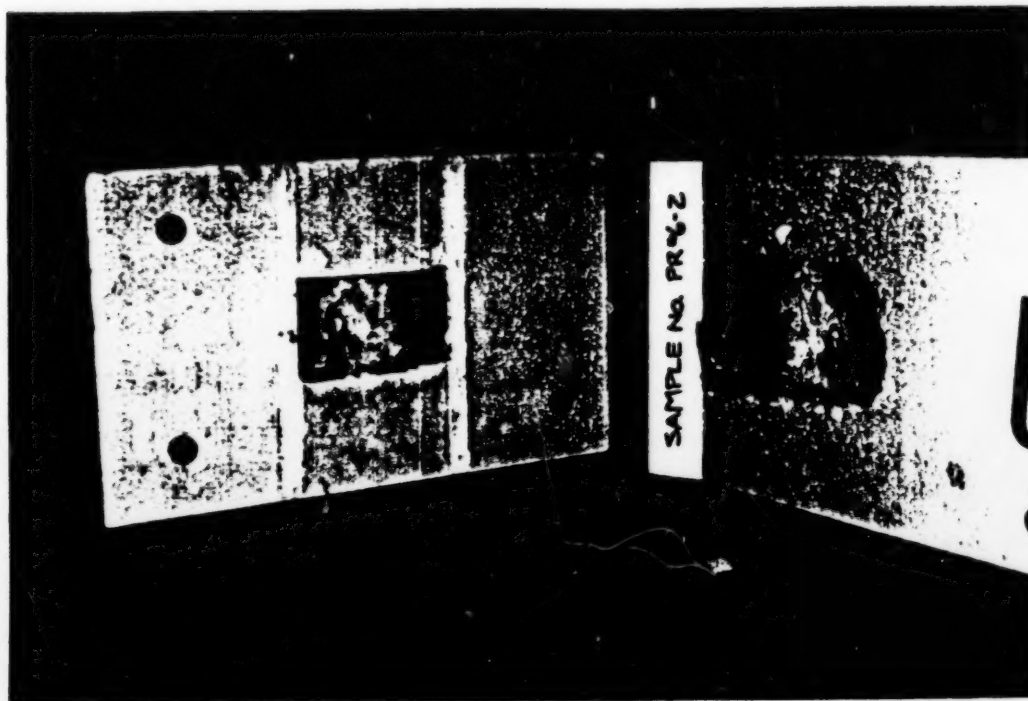


Figure 42: Sample No. PR 6-2 Before and After Shearing